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Stand Dynamics and Fire History of a Southern Appalachian Pine-Hardwood Forest on Rainy Mountain, Chattahoochee National Forest, Georgia, U.S.A.

Alex William Dye
adye6@utk.edu

To the Graduate Council:

I am submitting herewith a thesis written by Alex William Dye entitled "Stand Dynamics and Fire History of a Southern Appalachian Pine-Hardwood Forest on Rainy Mountain, Chattahoochee National Forest, Georgia, U.S.A.." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Geography.

Henri D. Grissino-Mayer, Major Professor

We have read this thesis and recommend its acceptance:

Sally P. Horn, Carol P. Harden

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

Stand Dynamics and Fire History of a Southern Appalachian Pine-Hardwood Forest on Rainy Mountain, Chattahoochee National Forest, Georgia, U.S.A.

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encouragement I would not have developed the courage and motivation to succeed in life. To them I am forever grateful.

ABSTRACT

In the American Southeast, forest managers and conservationists are interested in evaluating how forest composition is changing in response to both human and natural disturbances. This study explored the stand dynamics of a pine-hardwood forest on Rainy Mountain in the Chattahoochee National Forest of Georgia over the last 115 years and analyzed the role fire has had as a disturbance in the forest. Increment cores were collected from trees in 30 plots, each 0.01 ha in area. The cores were used to determine date of establishment of each tree and create age structure charts for each plot and for the study area as a whole. Based on calculated importance values, blackgum, pitch pine, and red maple are currently the dominant species in the forest. However, seedling and sapling surveys showed an absence of yellow pine regeneration along with a relative abundance of red maple and blackgum, indicating that these trees will dominate the future forest. A concurrent fire history was also constructed using logs, stumps, remnant wood, and living trees with fire scars. Small sections were collected from each and analyzed to determine how frequently fires occurred in the Rainy Mountain area. The resulting fire chronology, the first developed for the state of Georgia using dendrochronology, spans from 1904 to 2012 and includes 36 individual dated fire scars from 20 trees. Fires occurred as recently as 2010, and the mean fire interval of the chronology indicates a fire event approximately once every four years. Several old stumps with fire scars were also collected, but could not be dated in many cases because of the lack of a sufficiently long master tree-ring chronology. Similar to other research conducted in the southern Appalachian Mountains, this study shows a change in forest composition from a pine-oak dominated forest to a red maple-

blackgum dominated forest, a change that has previously been linked to fire suppression management policies beginning in the 1930s. However, the fire chronology at Rainy Mountain shows an actual increase in fire frequency after the 1930s accompanied by a concurrent change in forest composition.

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CHAPTER ONE

1. INTRODUCTION

Forests in the eastern United States are mostly temperate deciduous, and those of the southern Appalachian region naturally exhibit an oak-pine-hickory species composition (Braun 1950). Stand dynamics in the southern Appalachians are governed by several natural and human disturbances, including insects (Waldron et al. 2007), ice storms (Ashe 1918; Lafon and Speer 2002), landslides and geomorphic events (Bogucki 1976; White 2010), clear-cutting of forests for development and logging (Van Lear and Waldrop 1989), and fire (Harmon 1980). Ecologists recognize the important role disturbances play in forests, but a complete understanding of how different forms of disturbance interact with fluctuating environmental conditions to control the composition of a stand is still being developed. Continued study of individual stand characteristics and their accompanying disturbances contributes to this understanding and can inform management strategies of future forests. As the impacts of anthropogenic and natural disturbances have on the health of our forests become clearer, researchers and land managers increasingly focus on understanding how forest stands respond and reproduce in changing environments.

Stand dynamics focuses on the composition and interaction of plants in a stand, a localized aggregation, or community, of plants that live in relationship to each other and their environment (Oosting 1956). These plants compete for light, water, nutrients, and essential resources available in limited quantities, and those that can best tolerate the environmental conditions dominate the stand. Generally, in eastern forests, the dominant species are the taller, larger trees that make up the canopy (Braun 1950). In unmanaged forest communities, the outcomes of competition and dominance are naturally regulated and a natural disturbance event is needed to clear the forest and open opportunities for stand replacement (Oliver and Larson 1976). A disturbance is defined as an event that affects a stand by killing or harming all or some of its individual members (Oliver and Larson 1976). Violent winds, fires, glacial advance, and floods are examples of natural disturbances. But, disturbances can also be unnatural, and human interference has altered the natural disturbance patterns in forests.

Regardless of the cause of disturbance, an event that destroys plant life will open new space for species to colonize and take the place of those that were removed. New individuals that establish around the same time are termed an age class, or cohort. In a severe disturbance that kills most trees in a stand, new trees will establish throughout the stand at the same time. This new stand consists of one age class and is called an even-aged stand (Oliver and Larson 1976). Less severe disturbances may only leave portions of the stand open for colonization. In this case, trees establish in various years throughout the stand whenever minor disturbances create the opportunity. The trees in this type of stand are of different ages, and the stand is considered to be an uneven-aged or all-aged stand. Disturbances create unique situations by allowing plants that had otherwise been outcompeted in the mature community to colonize (Brokaw 1987).

Understanding the invasion of species into a cleared area after a disturbance is essential in the study of stand dynamics. Early ecological theory held that species invaded an open area in a strict and predetermined step-by-step progression, a concept known as "relay floristics" (Clements 1916). This theory has since fallen into disfavor, replaced by the concept of "initial floristics," in which all species begin colonization immediately and simultaneously after an opportunity becomes present (Egler 1954). The stand evolves and grows as the plants best adapted to different stages outcompete the others, and the stand eventually takes on a new composition largely composed of the dominant species. Long-term survival is limited to a select few individuals, as most individuals die young and fail to establish (Peet and Christensen 1982). Because so many natural and unnatural disturbances influence the dynamics of each stand, understanding the many facets of stand history is critical to efficiently manage the forest for the future. A major part of research on stand dynamics involves developing a history of successional development for an individual stand, with a central focus on past disturbances. While the broader regional forest may exhibit similar characteristics, local environmental conditions differ slightly between stands.

A typical study of stand dynamics is designed to quantify the successional development of trees in a forest. In such a study, all living and dead trees are sampled to quantify the past and present forest composition (Lorimer and Frelich 1989; Abrams et al. 1995; McCarthy et al. 2001). Determining the date of the inner ring of a tree approximates the establishment date of the tree, the year it invaded after a disturbance (Abrams and Nowacki 1992). An increment borer can be used to take a core from near the base of the tree, and the innermost ring can be accurately dated using dendrochronological dating techniques (Gutsell and Johnson 2002). Sometimes, evidence of a particular disturbance, such as basal scars formed from a fire injury, can be found on surrounding trees (Toole 1961).

Fire is a well-documented forest disturbance that has been shown to drastically alter the stand dynamics of entire regions over time (Abrams 1992; Cowell 1995; Bratton and Meier 1998;

Lorimer 2001). Fires influence regeneration by killing trees or burning through the understory, providing space for new tree establishment. Fires have been occurring for most of Earth's history, and humans have influenced fire regimes as their occupance patterns have changed (Fowler and Konopik 2007). Human influence on disturbance patterns in the United States has been well documented, especially in relation to fires (Chapman et al. 1982; Pyne 1982; Delcourt and Delcourt 1998), and even in the modern day (Zhang et al. 2008).

One of the most common ways humans have influenced fire is through an active campaign of fire suppression, which completely changes fire regimes by excluding fire as a vital ecosystem process. The absence of fire allows for growth of a tall, dense understory that increases resource competition and hinders development of new trees (McDonald et al. 2003). Fire suppression has negatively affected the pine-oak forests of the southern Appalachians, as fire-tolerant trees, such as pines and oaks, are failing to sufficiently regenerate in the absence of fire (Hubbard et al. 2004; Dumas et al. 2007). Forest composition is shifting away from pine-oak species towards fire-intolerant species such as blackgum (*Nyssa sylvatica* Marshall) and red maple (*Acer rubrum* L.) (Abrams 1992; Abella and Shelburne 2003). Mounting evidence confirms the pine-oak forest type is declining in the southern Appalachians and is likely to disappear entirely in the future (Knebel and Wentworth 2007).

Additionally, forest area is becoming increasingly discontinuous as residential areas and industry continue to expand. In the South, forested area has decreased from nearly 140 million hectares in the 1850s to under 84 million hectares in 2000 (USDA 2001). This alarming decrease and fragmentation of forest lands underscores the importance of understanding the changes that affect natural communities if we wish to maintain healthy forests for years to come.

Scientists have recognized the troubles plaguing the forests of the world today, and have spoken in favor of a broad geographical and historical perspective on the status of all ecosystems to ensure continued health for the natural environment into the future (Foster 2000). Studies of stand dynamics and disturbance histories can contribute a valuable spatial and temporal perspective on ongoing changes in our forests.

1.1 Research Questions

This project adds to the growing body of knowledge regarding stand dynamics and fire activity in northern Georgia, most of which include stand dynamics studies focused on regeneration of Table Mountain pine (*Pinus pungens* Lamb.) populations in relation to disturbances (Brose et al. 2002; Brose and Waldrop 2006; Brose and Waldrop 2010) and the effects of prescribed fire on regenerating yellow pine populations (Welch et al. 1999; Waldrop and Brose 1999; Elliott et al. 2000; Waldrop et al. 2000; Waldrop et al. 2003). These studies, accompanied by a single assessment that catalogued areas of old-growth forest in the Chattooga River watershed conducted from 1994–1995 by Forest Service personnel (Carlson 1995), have served as the main guides to forest structure and disturbance history in the northeastern districts of the Chattahoochee-Oconee National Forest (CONF). Covering 50 hectares of forest land in the Chattahoochee, Sumter, and Nantahala National Forests, the survey conducted by Carlson 1995 identified and mapped areas of old-growth forests and took note of how the stands seemed to be affected by nearby disturbances. While these studies are a useful starting point in studying forest structure in the CONF, more detailed studies of stand dynamics and disturbance history are needed to refine our understanding of the factors that influence the past, present, and future growth of forests in the CONF.

In this study of stand dynamics and fire history in the CONF, the following questions were addressed:

1) Have the stand structure and forest composition changed over the last several decades in the Chattahoochee National Forest?
2) Based on the past and present composition, dynamics, and structure of the current forest, which species are expected to be dominant in the Chattahoochee National Forest in the future?
3) How often have fires occurred in the recent past at Rainy Mountain, and what implications does the occurrence or lack of occurrence of fires have for the stand dynamics, structure, and composition of the forest?

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Fire History Research in the Southern Appalachian Mountains

Using physical evidence of fires on living and dead trees in the form of fire scars is one of the most common ways of reconstructing past fire patterns (Leopold 1924; Gutsell and Johnson 1996). The field of dendrochronology provides a unique contribution to fire studies with the use of crossdating techniques to date fire scars (Madany et al. 1982). Extensive fire history research has been conducted in the dry and arid western U.S., where large, low severity fires were common prior to ca. 1880 (Baisan and Swetnam 1990; Touchan and Swetnam 1995; Grissino-Mayer et al. 2004; Miller et al. 2009). However, fires are actually more frequent in the southern U.S. (Gramley 2005). Fire histories in the humid eastern U.S. are less common, mainly due to the insufficient availability of usable trees caused by tree decay, tree removal, and human manipulation of forests (Aldrich et al. 2010).

The importance of fire history studies to forest conservation and management has sparked an interest in fire history, and a growing number of studies are being conducted to expand the network of fire information in the eastern U.S. These include studies in Maryland (Shumway et al. 2001), Louisiana (Stambaugh et al. 2011), the Ozarks of Arkansas (Guyette and Spetich 2003; Stambaugh et al. 2005; Guyette et al. 2006), Florida (Huffman et al. 2004; Henderson 2006), and Illinois (Robertson and Heikens 1994). Additionally, an increasing number of studies have been performed to reconstruct the history of wildfires in the southern Appalachian Mountains, including the montane regions of Virginia (Sutherland et al. 1995;

DeWeese 2007; Lafon and Grissino-Mayer 2007; Hoss et al. 2008; Aldrich et al. 2010), Tennessee (Harmon 1982; Armbrister 2002; Feathers 2010; LaForest 2012), West Virginia (Schuler and McClain 2003; Lynch and Hessl 2010; Hessl et al. 2011), and North Carolina (Dumas et al. 2007) as researchers work toward developing a regional understanding of fire patterns. Additionally, several researchers have used public records of fires and accounts of past droughts, severe weather, and human settlement patterns to characterize the historical fire patterns of the Appalachians and southeastern U.S. (Bratton and Meier 1998; Mitchener and Parker 2005; Fowler and Konopik 2007).

The behavior of fire in the United States is intricately linked to the activities of humans (Pyne 1982; Williams 1989), and long-term records of fires developed through analyzing charcoal in sediment profiles show burning in concert with Native American agricultural practices (Chapman et al. 1982; Delcourt and Delcourt 1998). Additionally, the type of human activity present on the landscape has a major impact on the characteristics of fire activity. Fowler and Konopik (2007) outlined five main stages of anthropogenic influence in the fire regimes of the southeastern U.S.: Native American Prehistory, Early European Settlers, Industrialization, Fire Suppression, and Fire Management. Forests entered the fire suppression stage when forest conservation passed under federal control in the 1930s, and are currently in the fire management stage.

Ethnohistorical accounts of travelers are another prominent source of information about early settlement fires. The noted naturalist and explorer William Bartram mentioned in several accounts witnessing what appeared to be natural- and Native American-induced fires during his travels through areas of northern Georgia and southwestern North Carolina (Harper 1998).

The prominent surveyor Andrew Ellicott also noted fires near the Chattooga River in Georgia and South Carolina (Mathews 1908), as did the Spanish conquistador Hernando de Soto (Sheppard 2001). These accounts reinforce the understanding that fire has been a part of the southeastern forests for a long time.

In the 1880s, the southeast experienced rapid industrialization as the Industrial Revolution took hold throughout the U.S. Local residents engaged in rampant slashing and burning of the forest to make way for more agriculture, railroads, timber, and roads (Van Lear and Waldrop 1989). This was an era of widespread logging, often followed by high intensity, stand-replacing fires (Brose et al. 2001). After clear-cutting a forest, the land was often turned into pasture land, preventing reestablishment of the forest (Van Lear and Waldrop 1989). If the clear-cut land was abandoned, however, the leftover slash quickly dried and usually caught fire, ignited by sparks from passing steam engines. Subsequent soil erosion decreased the viability of the soil (Brose et al. 2001).

This depletion of forest resources went largely unchecked, as forest management was not a priority. But, as early as 1895, William Ashe recognized the conservation risks to future forests by the lack of thoughtful management of southeastern forests. With the founding of the United States Forest Service in the early 1900s, a central focus of forest management was to control fires by active suppression (Williams 2002). In 1937, the USFS introduced a public campaign to educate the public about fire dangers, famously aided by Smokey the Bear. Nationwide, the total area burned by forest fires decreased from 20.25 million ha in 1930 to 0.8 million ha in 1960 (MacCleery 1992). In Great Smoky Mountains National Park, Harmon (1982) found that the mean fire return interval increased from 12.7 years before 1940 to 20.0 years after

1940. LaForest (2012) found that fires were common in Great Smoky Mountains National Park before the area passed under federal regulation, even during Native American and European settlement. However, after the park was founded and fire suppression policies enacted, the frequency of fire events decreased.

As the importance of fires to natural ecosystems is better understood, forest workers are adopting an attitude of fire management rather than of fire exclusion, and fire history studies play an essential part in developing the most effective plans for fire management. Predicting the failures of fire suppression, Greene (1931) and Stoddard (1935) advocated the use of prescribed burning in the southeast to try to maintain some semblance of the natural state of the forests. In the 1980s, prescribed burning was first introduced into the southern Appalachians, and the effect of prescribed burns on the forest continues to be a major question in fire research in the region. Ecologists agree that fire needs to be introduced into Appalachian forests, but the correct strategies for doing so remain unclear (Buckner and Turrill 1998; Harrod et al. 1998). The propagation of native southern Appalachian tree species, such as yellow pines, has been linked to fire activity (Zobel 1969; Sutherland et al. 1995), and several studies have been conducted using prescribed burns to determine the characteristics of fire (size, frequency, intensity) necessary for optimal yellow pine regeneration (Waldrop and Brose 1999; Elliott et al. 1999; Waldrop et al. 2000; Welch et al. 2000; Waldrop et al. 2003).

For example, Waldrop and Brose (1999) conducted prescribed burns on national forest land in northern Georgia to study the effects of fire intensity on regeneration of Table Mountain pine (*Pinus pungens* Lamb.). They observed how the forest regenerated after controlled burns over a 350 ha area at four different intensity levels. Pines regenerated in abundance after low and medium-low intensity fires, but the disturbance did not kill enough overstory trees to open the forest floor to new tree growth. However, high intensity fires killed too many overstory trees and possibly destroyed some seeds. The study concluded that medium-high intensity fires were optimum for yellow pine regeneration, as they killed some overstory trees but also allowed seedlings to take root.

Waldrop et al. (2003) further evaluated the possibilities of prescribed burning for aiding Table Mountain pine regeneration at three sites in the Chattahoochee, Pisgah, and Sumter National Forests. This study concluded that while medium-high intensity fires still appear to maximize pine regeneration and minimize overstory mortality, fires of all intensities do little to control competition from hardwood and shrub regeneration. Little is known about the ability of Table Mountain pine seedlings to compete against seedlings of other species, and the authors suggested that frequent low to medium intensity fires may be necessary to prevent regeneration of fire- intolerant species.

Brose and Waldrop (2006) and Brose et al. (2002) used dendrochronology to study age structure and tree recruitment trends in association with disturbance events. Brose et al. (2002) studied three ridgetop pine stands in the Chattahoochee National Forest and found that single, high intensity, stand-replacing fires may not be optimal for pine regeneration as was recognized by Elliott et al. (1999) and Welch et al. (2000). Rather, a series of medium intensity fires may be sufficient to open pine seeds without killing all the overstory while continuously inhibiting hardwood and shrub seedling survival. Brose and Waldrop (2006) confirmed these results at nine sites in Georgia, Tennessee, and South Carolina, but recognized that much more research was needed to fully grasp the type of fire needed to regenerate yellow pines in southern Appalachian forests.

Brose and Waldrop (2010) used a disturbance-succession model to study the responses of pines and oaks to disturbances by reanalyzing the same nine sites originally analyzed by Brose and Waldrop (2006). They showed that pines and oaks were largely failing to regenerate, a trend also confirmed by previous studies and attributed to a cessation of fires and disturbances and the growth of a dense shrub layer in the forest understory. They also concluded that oaks and pines regenerated most successfully following a fire combined with a canopy disturbance. While the exact characteristics of the fire regimes needed to facilitate pine and oak regeneration may remain unclear, it is widely accepted that fires are required. Correct use of prescribed burning can facilitate regeneration of these species, and research investigating the regeneration of species following burns contributes to developing a management strategy for using fire to preserve the pine-oak forest type.

2.2 Research on Stand Dynamics in the Southern Appalachian Mountains

Research on stand history assesses changes in vegetation over time. Most stand histories involve disturbances, both natural and human caused, to the stand. In the southern Appalachian region as a whole, the historical pine-oak forest type is declining (Harrod et al. 1998; Vose et al. 1999). This changing vegetation composition of the Appalachians creates problems for total vegetation diversity (Waldrop et al. 2003), wildlife (Trani 2002), and natural resource availability and quality for humans (Christensen 1996). The suppression of wildfire, an otherwise natural disturbance in forests, is likely a leading cause of these changes (Dumas et al. 2007).

Research on stand dynamics is relatively sparse in the deciduous forests of the eastern U.S., in large part because mature stands are rare and large portions of necessary evidence have been removed by logging or land clearing (Lorimer 1980). Lorimer (1980) investigated an area of mature forest in the Joyce Kilmer Memorial Wilderness of southwestern North Carolina. He established a number of moderate-sized plots to achieve a broad spatial picture of the effects of disturbances on stand regeneration. He identified growth releases associated with disturbances caused by fire, windfall, and chestnut blight. Disturbances of sufficient intensity can kill trees and form canopy gaps, which are small openings in the stand created by one or more treefalls (Watt 1947). Gaps create openings that favor the establishment and survival of species that can subsist on intermediate light levels and survive as members of the understory for several years before reaching the canopy (Runkle and Yetter 1987).

Clebsch and Busing (1989) studied the successional dynamics in canopy gaps in middle-elevation hardwood forests in Great Smoky Mountains National Park. Their aim was to compare gap succession in old-growth forests to that in secondary forests that had regenerated in areas previously cleared. Again, they found that infrequent disturbances of windfall and fire played important roles in opening gaps. In the secondary forest, they found a higher percentage of regeneration of red maple (*Acer rubrum* L.), eastern hemlock (*Tsuga canadensis* L.), and tulip poplar (*Liriodendron tulipifera* L.), suggesting a shift away from the oaks and pines present in the old-growth canopy.

Phillips and Shure (1990) studied regenerative stand dynamics in the Nantahala National Forest near Highlands, North Carolina on sites logged in the 1980s. Whereas the prior forest (noted by the forest type of the surrounding non-logged areas) was characterized by a dominance of oak (*Quercus rubra* L., *Q. coccinea* Münchh., *Q. montana* Willd., hickory (*Carya cordiformis* (Wangenh.) K. Koch, *C. ovata* (Mill.) K. Koch, *C. tomentosa* (Lam. ex. Poir) Nutt., *C. glabra* (Mill.) Sweet), and tulip poplar, recent regeneration in the logged sites consisted of large numbers of red maple and black locust (*Robinia pseudocacia* L.). As expected, a greater diversity of species regenerated at sites with larger canopy gaps. This follows the principle that larger gaps increase the light and resource availability, and thus encourage a succession to higher diversity of plant species (Bormann and Likens 1979). Similar to Runkle (1990) and Lorimer (1980), the authors suggested that treefalls caused by fire and strong winds were the main causes of natural gap formation in the southern Appalachians.

Both DeWeese (2007) and LaForest (2012) found a transition from pine-oak dominated forests to red maple-blackgum dominated forests beginning in the 1930s. DeWeese (2007) focused on the decline of Table Mountain pine stands in the Jefferson National Forest in southwestern Virginia, linking their decline to an absence of fire resulting from fire suppression policies enacted by the national forest. Stands of mature Table Mountain pine are still present in southwestern Virginia, but the young trees and saplings growing in the understory indicate that Table Mountain pine will eventually succeed to fire-intolerant species such as red maple and blackgum. LaForest (2012) studied stand dynamics of three sites in western Great Smoky Mountains National Park from 1800 to 2012. The study showed consistent reestablishment of yellow pines and oak from the early 1800s to early 1900s, with a dramatic decline evident after the 1930s. In years since 1930, new tree establishment was found to be almost exclusively white pine (*Pinus strobus* L.), red maple, blackgum, and eastern hemlock. The study concluded that the current stands of mature yellow pines are likely the last to be seen naturally in the park and the forest composition will continue to trend towards dominance by fire-intolerant species such as white pine and red maple.

The pine-oak stands of the eastern U.S. are experiencing unnatural changes, including the decline and endangerment of Table Mountain pine in the Appalachians (Williams 1998) and the decrease in the historically fire adapted pine-oak forests of the eastern deciduous forests (Abrams 1998). Studies of stand dynamics in the southern Appalachians continue to provide evidence of a changing forest dynamic, an occurrence that is best understood in association with the corresponding changes in disturbances in the forest.

2.3 Fire and its Effects on Stand Dynamics

To completely understand stand dynamics, the disturbances that occur within the stand must be determined. After a fire sweeps through a stand, an injury called a fire scar can be left at the base of the tree. Later, the years of fire events can be determined by associating each scar with an annual growth ring in the tree that can be dated to its exact year of formation (Toole 1961; Fritts 1976; Richardson 1998). Fire scars will only develop if the fire is intense enough to injure the tree, but not intense enough to kill it (Lachmund 1921).

Forests of the southern Appalachian region developed in association with fire. In particular, Table Mountain pine and pitch pine have been shown to depend on fire for regeneration (Zobel 1969; Barden 1979; Williams 1998; Welch et al. 2000). Table Mountain and pitch pine have serotinous cones, meaning that the cones will open to release seeds under high levels of heat. Therefore, in the event of regular fire disturbances, these pines are better adapted to frequent fire than their competitors. However, in the absence of fire, other species have a better opportunity to compete. The natural disturbance regimes that had shaped the stands for years were interrupted with the onset of fire suppression in the 1930s, and yellow pine populations are decreasing, in part because of the absence of fire (Williams 1998).

Historically, many natural fires in the southern Appalachians were ignited by lightning, and were generally short-lived and of low intensity because of rain from thunderstorms (Mitchener and Parker 2005). Barden and Woods (1973) concluded that most lightning fires in the Great Smoky Mountains did not burn long and intensely enough to remove the forest canopy and allow for complete regeneration of a stand. However, they also found that several instances of intense burns cleared the canopy on xeric, steep, south-facing slopes with high drainage and insolation, so called "hotspots" of regeneration. Even after less intense fires, they found that damage and mortality to hardwoods was much greater than that to pines, and that hardwood regeneration was limited on these sites. This conclusion is similar to that of Whittaker (1956), who found that the time required for oak to fully replace pine on xeric slopes was longer than the average fire interval. Barden and Woods (1973) included only the previous 80 years, which included no years of intense drought. They hypothesized that a severe drought occurring once every 150 to 300 years could instigate fires intense enough to foster widespread regeneration of pines.

Harrod et al. (2000) studied the effects of fire frequency on the diversity of forest understory in southeastern Tennessee. They compared sites that had burned recently with sites that had not burned since before fire suppression began. As expected, they found less diversity with less fire. The unburned sites also exhibited a shift in species regeneration, with species such as red maple appearing in the understory rather than the typical pine-oak of the burned forests. Other recent studies also confirmed the effects of fire on the diversity and regeneration of the understory of the southern Appalachians (Reilly et al. 2006; Dumas et al. 2007).

The effects of fire on stand regeneration are also studied by observing how the stand responds to an intentional prescribed burn. Elliott et al. (1999) conducted burns at ridge, midslope, and low slope locations and quantified the response of the vegetation based on measurements taken before and after the burns. At the pine-oak ridge sites, they observed a lack of tree diversity and a high density of mountain laurel present in the understory. The mountain laurel was killed in the fire, but quickly regenerated. The size of the prescribed fire had little effect on species diversity due to low rates of tree death.

Welch et al. (2000) conducted a similar study, but at a more regional scale that included the forests of northern Georgia, southeastern Tennessee, and southwestern North Carolina. They focused specifically on Table Mountain and pitch pine communities. Prior to prescribed burns, they saw virtually no pine seedlings in the understory. Post-burn forests had more understory diversity, including pine seedlings. However, these were deemed unlikely to survive in the long-term because of the shade from the canopy, and they concluded that future burns must open up the canopy more completely to facilitate full regeneration.

DeWeese (2007) studied fire history in the forests of southwestern Virginia, emphasizing the relationship between fire regimes and climate. Using scarred yellow pine trees (with specific focus on Table Mountain pine), she reconstructed fire history back to the late 1700s. She found evidence linking yellow pine and oak recruitment to fire events. During several periods following fire events recorded by trees, she noticed a peak in recruitment of yellow pines and oaks. Since the adoption of fire suppression policy in the mid-1900s, few yellow pines have established. The last fire recorded by a tree at any of the study sites was in 1976. The forest has thus been 36 years without a fire, providing strong evidence for the necessity of fire in maintaining yellow pine populations.

Feathers (2010) conducted a fire history/stand dynamics study on two sites near Cades Cove in Great Smoky Mountains National Park. His study showed that, historically, most fires occurred as low-severity surface fires. Although he did find evidence of a few widespread fires, synchrony of fires between sites was rare, showing that most fires were confined by topography. His results indicated a fairly short fire interval (every 3 to 6 years) prior to the formation of the national park. Additionally, he found a shift in species composition related to fire suppression. Fire-tolerant species, including Virginia and pitch pine and oaks, ceased establishment after the 1930s–1940s, while fire-intolerant species, particularly blackgum, eastern white pine, and red maple, have been establishing continuously since the 1940s.

LaForest (2012) studied the fire history and stand dynamics of the mixed hardwood/pine forests in the western part of Great Smoky Mountains National Park, using some of the oldest trees yet found in the southern Appalachians. The older trees at her study sites allowed for a fire and stand reconstruction reaching back 300 years, rare in the southern

Appalachians because of the lack of old-growth forests. Her research confirmed that compositional shifts in the forest were related to changes in the fire regime. She identified three periods in historical fire activity: pre-European settlement, European settlement, and national park protection. Forests were dominated by yellow pine and oaks throughout the first two periods, with fires occurring more frequently. After 1934, the mean fire interval increased, accompanied by growth of a dense understory and increased dominance of fire intolerant species such as red maple and blackgum.

CHAPTER THREE

Stand Dynamics and Fire History of a Southern Appalachian Pine-Hardwood Forest on Rainy Mountain, Chattahoochee National Forest, Georgia, U.S.A.

This chapter is intended for submission to the journal *Forest Ecology and Management*. The research topic was originally developed by me and my advisor and second author, Dr. Henri Grissino-Mayer. The use of "we" throughout the text refers to me and Dr. Grissino-Mayer, who assisted with site selection, project development, and text editing. My contributions to this chapter include field collection, processing and dating of samples, data analysis, interpretation and graphic displays of results, and writing of the manuscript.

3.1 Introduction

The status of forests in the eastern United States is a concern for forest managers who wish to monitor how changing environmental and human conditions influence the structure and composition of the forests and patterns of forest disturbance. The southern regions of the Appalachian Mountains of Virginia, West Virginia, North Carolina, Tennessee, and Georgia naturally exhibit a pine-hardwood forest, composed predominantly of yellow pines (*Pinus echinata* Mill., *Pinus pungens* Lamb., *Pinus rigida* Mill., *Pinus virginiana* Mill.) and oak (*Quercus rubra* L., *Quercus coccinea* Münchh., *Quercus montana* Willd.). However, research conducted over the last 20 years has shown evidence of the decline of this traditional forest composition accompanied by an increase in species such as red maple (*Acer rubrum* L.), blackgum (*Nyssa sylvatica* Marshall), and eastern white pine (*Pinus strobus* L.) (Abrams 1992; Harrod et al. 1998; McDonald et al. 2003). For example, Abella and Shelburne (2003) found a marked increase in recruitment of eastern white pine relative to other species since 1950 in a South Carolina forest dominated by old-growth oak trees. DeWeese (2007) found a similar surge in white pine recruitment in southwestern Virginia, accompanied by widespread recruitment of red maple and blackgum and a decline in yellow pine regeneration. In Great Smoky Mountains National Park, Feathers (2010) and LaForest (2012) both found forests once dominated by yellow pines and oaks to be undergoing a transition to forests composed primarily of red maple, blackgum, and white pine.

Changing species composition has often been linked to changing patterns of forest disturbance, particularly that of fire. Shifting fire regimes have been shown to drastically alter the stand dynamics of entire regions over time (Barden and Woods 1976; Abrams 1992; Cowell 1995; Lorimer 2001; Aldrich 2010). Changes in fire regimes can be influenced by human activity, which has been affecting the natural occurrence of fire for centuries (Pyne 1982; Williams 2002; Fowler and Konopik 2007). Most recently, fire regimes have been altered through an active campaign of fire suppression enacted when the United States Forest Service assumed control of most forested land in the 1930s and 1940s. Fire suppression beginning in the mid-twentieth century has been associated with the decline of the pine-oak forest type throughout the southern Appalachian Mountains (Harrod et al. 2000; DeWeese 2007; Aldrich et al. 2010; Feathers 2010; LaForest 2012). Yellow pines and oaks are fire-tolerant species with specific adaptations, such as serotinous cones and thick bark, to survive repeated fires (Zobel 1969; Barden 1979; Abrams 1992; Waldrop et al. 2003). Fires can facilitate regeneration by killing trees or burning through the understory, providing space for new tree establishment, but the absence of fire allows for growth of a tall, dense understory, increasing resource competition and hindering regeneration of fire tolerant species (Brose and Waldrop 2006; Reilly et al. 2006; Brose and Waldrop 2010).

Several studies have been conducted in the southern Appalachians using prescribed fires of varying intensities to determine the characteristics of fire necessary for optimum yellow pine regeneration (Welch et al. 1999; Waldrop and Brose 1999; Elliott et al. 2000; Waldrop et al. 2003). Fire can influence the species composition of Appalachian forests, but the extent to which it does so remains an area of ongoing study. Evidence gained from studies of stand dynamics in the southern Appalachians show that the species composition of forests in the region is changing, and the pine-oak forest type is likely to disappear entirely in the future (Knebel and Wentworth 2007).

The Chattahoochee National Forest (CONF) is a unique location for a study of stand dynamics coupled with fire history. Located at the southern edge of the Appalachian Mountains, the land covered by the CONF is the beginning of a physiographic transition from mountains in the north to the lowland pine savanna and piedmont region to the south. The region has experienced substantial alterations by Native Americans and European settlers eager to extract resources and extend the frontier into the mountains, and natural fire regimes have been changed as a result (Williams 1989). Additionally, the CONF includes the southernmost area of the Appalachian pine-oak forest type, including the declining yellow pines. The nexus of environmental transition and an ongoing history of human involvement in the CONF make a solid understanding of stand dynamics and fire history in the region an integral addition to the growing network of studies in the southern Appalachians.

The purposes of this study are to determine how the species composition of forests in the Chattooga District of the CONF is changing and to provide an initial assessment of the composition of future forests using a study site that is typical of forests in the CONF.

Additionally, the study uses dendrochronology to reconstruct the fire history on Rainy Mountain to determine how fire activity is changing and how it has influenced stand dynamics. This research combines stand dynamics with a detailed fire history to contribute to a growing body of studies of forest composition in northern Georgia (Welch et al. 1999; Brose et al. 2002; Brose and Waldrop 2006; Brose and Waldrop 2010). Rainy Mountain was chosen for this study for its mixture of old, medium, and new growth trees, which is representative of the larger forest. Three study sites were selected at Rainy Mountain, and results from each compiled to draw conclusions for Rainy Mountain as a whole. In this study, we address the following research questions:

1) Have the stand structure and forest composition changed over the last several decades in the Chattahoochee National Forest? Why or why not?
2) Based on the past and present composition, dynamics, and structure of the current forest, which species are expected to be dominant in the Chattahoochee National Forest in the future?
3) How often have fires occurred in the recent past at Rainy Mountain and what implications does fire activity have for the stand dynamics, structure, and composition of the forest?

3.2 Study Site

The Chattahoochee-Oconee National Forest was founded in 1936, although pockets of the area were under the supervision of the Cherokee/Nantahala forests as early as 1911.

Currently, most of the forested land in northeastern Georgia is federal land (Figure 3.1) which includes the southernmost reaches of the Appalachian mountain chain. The natural forest composition is an oak-pine-hickory combination (Braun 1950). Additionally, this area includes the southernmost range of Table Mountain pine (*Pinus pungens* Lamb.), which exists in pockets at higher elevations.

Federal commercial logging likely started in the late 1930s after the CONF became an official unit of the United States Forest Service (USFS), but no detailed federal records of logging history are available for the CONF. Nonetheless, human disturbance in northern Georgia has been occurring for centuries, and the region has a history of intense resource depletion by settlers as early as the 1800s. Examples of such resource extraction practices include logging, gold mining, extensive clear cutting, extensive hunting of wildlife, and over-grazing of livestock (Williams 1989; Silver 1990; Harper 1998; Fowler and Konopiak 2007). Thus, the forests of the CONF today are the product of years of repeated human interference.

The stand dynamics and fire history of the southern Appalachian pine-hardwood forest were studied in the Chattooga Ranger District, the easternmost district of the CONF. The Chattooga District is bordered on the east by the Chattooga River and South Carolina and on the north by North Carolina. Sampling sites for this study were centered on the locality of Rainy Mountain (elevation 898 m). Rainy Mountain is adjacent to the Bartram Trail, a moderately used 184-km footpath, and is approximately one km south of the Warwoman Wildlife Management Area and 9 km east of the town of Clayton, Georgia. Fieldwork was conducted at three sites on Rainy Mountain (Figure 3.2).

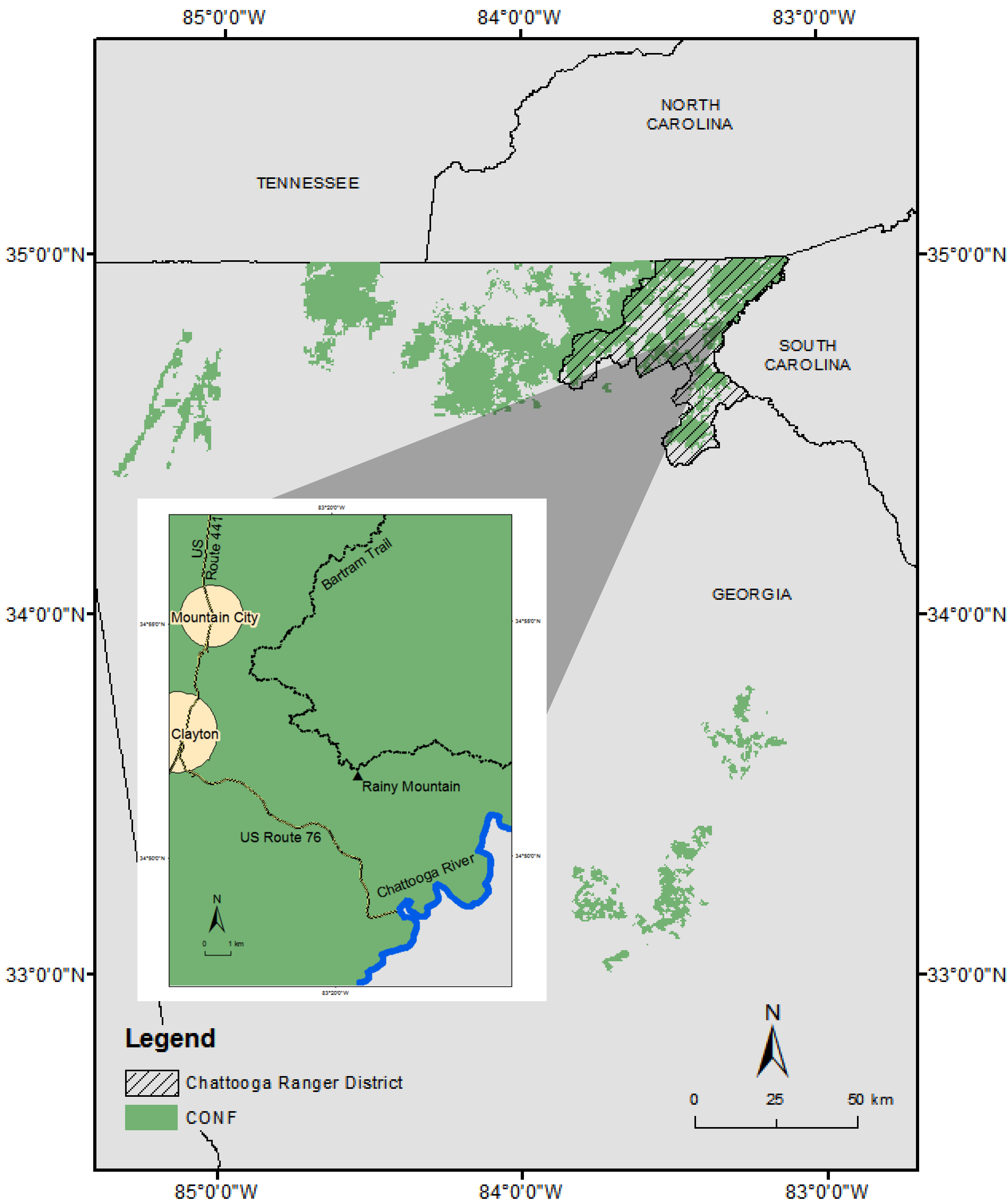

Figure 3.1: Map showing lands managed by the Chattahoochee-Oconee National Forest (CONF) and the Chattooga Ranger District. Inset map shows the location of Rainy Mountain. Map was created by the author. Shapefiles for state boundaries, roads, and towns were obtained from census.gov, and shapefiles for USFS land were obtained from the CONF.

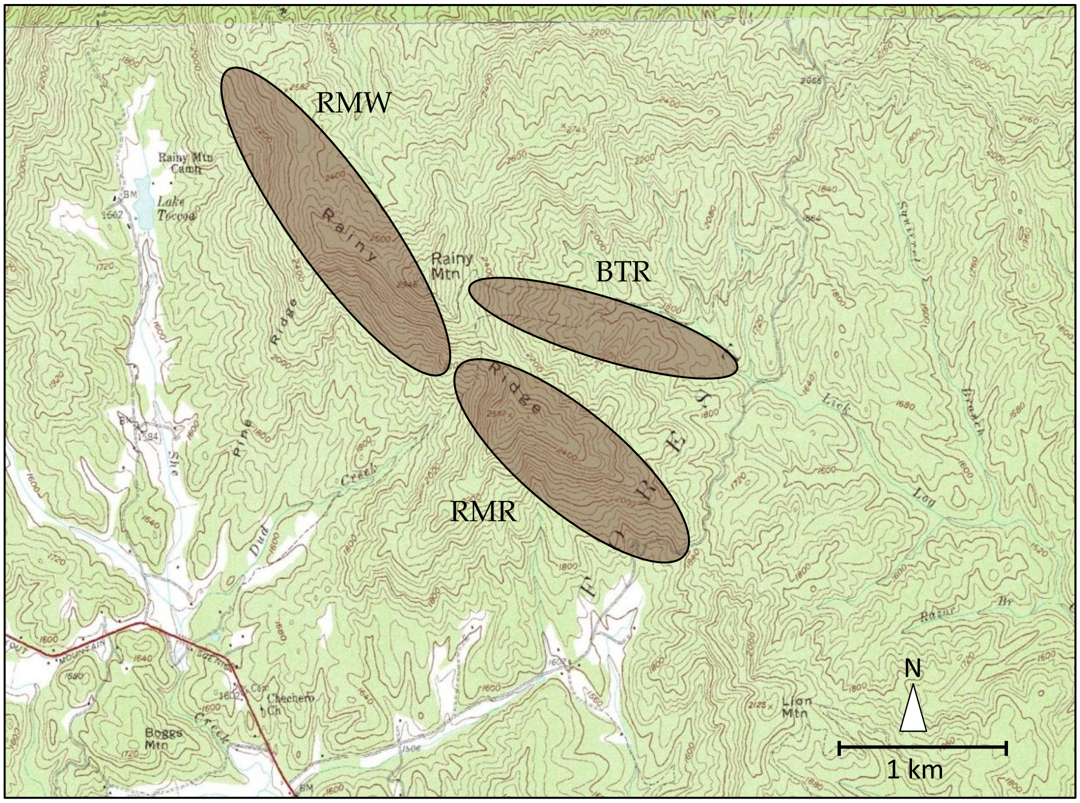

Figure 3.2: Map showing the three Rainy Mountain study locations: Bartram Trail (BTR), Rainy Mountain Ridge (RMR), and Rainy Mountain West (RMW).

The Bartram Trail (BTR) site is in a medium to old-growth forest to the northeast of the Rainy Mountain summit. Sampling plots were set up along the south-facing slope downhill from the Bartram Trail. This slope is moderately steep and is marked by a series of intermittent stream channels carved out down the slope. The Bartram Trail follows an old logging track over an east-west ridge leading up to Rainy Mountain. The forest is characterized by an abundance of blackgum and red maple, widespread mountain laurel (*Kalmia latifolia* L.) with thick trunks, and some mature yellow pines. The duff layer on the forest floor is thick, and walking through the forest involves wading through deep piles of leaves, many decaying logs, fallen branches, and other organic matter. Evidence of logging was obvious. Several skid roads were present, as well as many unmarked trails and roads leading off the main path. Evidence of logging in the form of old stumps existed to about 50 m below the top of the ridge.

The Rainy Mountain Ridge (RMR) site was located on a southeast-to-northwest-oriented ridge from Poole Creek Road at the lowest elevation to just below the Rainy Mountain summit. The forest is characterized by younger trees, including some yellow pines. Significant disturbance was observed at the site, namely an abundance of trees killed by southern pine beetle and felled hardwoods, perhaps caused by wind throw. Fire scars were present on many of the pine trees on the ridge, and char at the base of trees and dead, blackened hardwoods indicated that fires had passed through recently. The ridge was thin and exposed, with steep slopes on either side. The forest floor was open because of the large number of dead trees. Evidence of logging was not as abundant as at the Bartram Trail site, but a few logged stumps were present and traces of an old logging road were visible along the crest of the ridge.

The Rainy Mountain West (RMW) site was located on a southeast-to-northwest-oriented ridge northwest of the Rainy Mountain summit. The forest was characterized by medium and old-growth hardwoods and yellow pines. Very little evidence of natural disturbances was observed, but the RMW site had the most extensive network of logging roads of the three sites. No fire scars were found, and the remains of logged stumps were scarce. The RMW site has some of the largest yellow pines observed at Rainy Mountain, with diameter-at-breast-height measurements up to 65 cm.

3.3 Methods

3.3.1 Field Methods

Plots 0.01 ha in size were laid out at each of the three Rainy Mountain sites. Plots were selected to ensure that a representative portion of the forest was sampled using coordinates selected using Google Earth imagery (Figure 3.3). Ten plots were selected near the Bartram Trail site (BTR), eight plots on the Rainy Mountain Ridge site (RMR), and 12 plots on the southwest slope of Rainy Mountain (RMW) for a total of 30 plots. More plots were placed at the largest site (12 at RMW), and fewer plots at the smallest site (8 at RMR) to cover the sampling area of Rainy Mountain. Using the coordinates taken from Google Earth, a GPS was used to find these locations in the field, marking the center of each plot with a stake. Notes were taken describing the site characteristics, including slope aspect, associated vegetation, dominant understory plants, and thickness of the duff layer. Additionally, evidence of disturbances such as fire, logging, and insect outbreaks were noted as influences on stand history.

Using the stake as the center, a circular plot was established by laying out two perpendicular transects of 11.28 m (0.01 ha in area) with a measuring tape (Figure 3.4A). Each tree in the plot boundary with a diameter at breast height (DBH) greater than 5 cm was flagged and identified by species, dbh was recorded, and an ID number was assigned. Only trees with canopy potential were flagged. Each tree was cored at 30 cm above ground height (Figure 3.4B), and each core was placed in a straw, labeled, and stored in map tubes to be transported back to the laboratory.

Seedlings and saplings were surveyed in each plot. Plants taller than 1 m but with a dbh less than 5 cm were classified as saplings, and all smaller plants classified as seedlings. Because of the large number of seedlings and saplings, the plots were divided into four quadrants to more accurately locate and tally the plants by a visual count. All four quadrants were added together to obtain a seedling and sapling count for the entire plot. Each seedling and sapling was identified according to species. Because of the similarity in appearance of the three red oak species (scarlet oak, red oak, and black oak) when young (identification primarily by leaf traits), all red oak seedlings and saplings were classified as one category called "red oak."

Additionally, extensive scouting was conducted to identify fire scars on stumps, remnant wood, and living trees (Figure 3.5A and 3.5B). Once identified, these were flagged and mapped with a GPS and a cross section obtained from each using a chainsaw. The cross sections were obtained using a standard plunge-cut method to extract small wedges from large trees and entire cross sections from samples of lesser diameter (Arno and Sneck 1977). Each cross section was carefully wrapped and transported back to the laboratory.

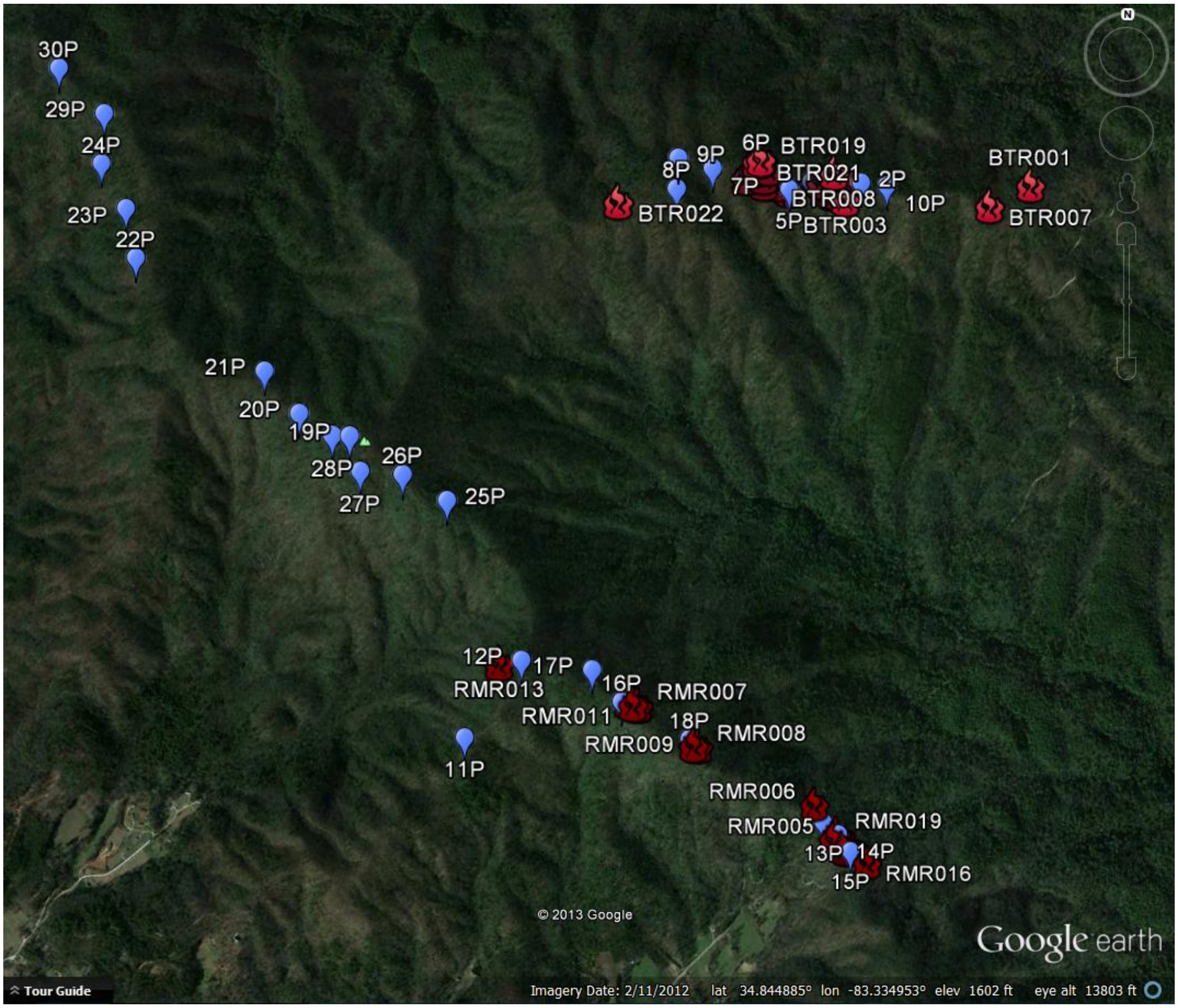

Figure 3.3: Google Earth image showing the locations of each of the 30 study plots at Rainy Mountain (blue tag) and the locations of collected fire scars (red flame tag).

A)

B)

Figure 3.4: (A) Layout of plot 6 at the BTR site. (B) Coring a large pitch pine tree at plot 11 at the RMR site.

A)

B)

Figure 3.5: (A) Example of a catface fire scar is shown at the base of a pitch pine tree at the RMR site. (B) Fire scars are present on the remains of an old logged stump at the BTR site.

3.3.2 Laboratory Methods

In the laboratory, each core was mounted and sanded using progressively finer sandpaper, starting with ANSI 180-grit and ending with ANSI 400-grit, allowing for maximum visibility of the cellular structure of the wood (Stokes and Smiley 1968; Orvis and Grissino-Mayer 2002). The rings on each core were then counted, the pith date determined, and the rings visually crossdated with a regional chronology using the list method (Yamaguchi 1991). All tree dates and identification information were entered into an Excel spreadsheet.

The establishment dates of the trees in each plot were used to create age-structure graphs. These graphs show the age distribution of the trees for each of the three main study areas, and for the Rainy Mountain forest as a whole using all 30 plots. High points on graphs of this type represent peaks in tree establishment. The dates of these spikes in recruitment were compared with fire scar information obtained from cross sections collected during this study and USFS documentation of past fires to determine whether tree recruitment is influenced by fire occurrence.

The age structure information also provided evidence of past and present changes in forest composition. Seedlings and saplings represent the new generation of trees. While the large trees in the plot represent the current composition of the canopy, the seedlings and saplings, as well as the smaller trees, provide insight into the future status of the forest canopy. To quantify species dominance at the sites, forest mensuration statistics were calculated using methods described by Matthews and Mackie (2007). Values of relative frequency, stand density, relative stand density, basal area, stand dominance, relative stand dominance, and importance values were calculated for each species in the stand.

Relative frequency was calculated by dividing the frequency of a species (number of plots where a tree species was found divided by the total number of plots at the site) by the combined frequency of all species and multiplying by 100. Relative stand density was calculated by dividing the stand density of a species by the average number of total trees per plot and multiplying by 100. Relative stand dominance was calculated by dividing the total basal area of a tree species (m^2) by the total basal area of all trees and multiplying by 100. Importance values were calculated on a 300-point scale by adding relative frequency, relative density, and relative dominance of each species. Final importance values were listed as a percentage relative to the 300-point scale. Higher importance values indicate dominance of a species within a stand (Matthews and Mackie 2007).

The cross sections with fire scars were processed similarly to the cores. Cross sections in weak condition or broken into several pieces were glued to a plywood mount before sanding to ensure structural integrity. Once sanded, the rings were counted and the fire scars marked to their corresponding ring. Because many of the cross sections came from stumps missing outer rings caused by decay over time, the sections were crossdated with the rings of cores and cross sections taken from living pine trees for which the outer ring date was known.

Fire-scarred samples collected from both living trees and stumps were processed. Samples from living trees had an outer ring date of 2012, allowing fire scars from these samples to be assigned an accurate date. A ring-width chronology of yellow pines collected from the Rainy Mountain sites was created from cores and cross sections to assist dating the rings on the older stumps. However, because of the scarcity of old living trees, this chronology was not long enough to sufficiently overlap with most of the stumps. Therefore, fire scar dates could not be determined for many stumps and these samples were not used in further analyses.

After analyzing the fire scars, the year and season of each fire occurrence was entered into FHX2 software to determine the statistical distribution of the fire interval data and to evaluate fire regime characteristics (Grissino-Mayer 2001). Statistics for fire history were modeled using the Weibull distribution, rather than the normal distribution, to allow for more accurate representation of fire history information (Grissino-Mayer 1999). Relevant statistics were determined for fire history, including mean fire interval (average time between fires), standard deviation, and the coefficient of variation. A fire history chart was created by importing the FHX2 file into FHAES (Fire History Analysis and Exploration System), which allowed for easier graphing capabilities on a Windows 7 system. These charts were used to graphically portray and compare fire histories at both the BTR and RMR sites individually and at Rainy Mountain as a whole.

3.4 Results

3.4.1 Crossdating

Thirty-nine fire-scarred samples were collected from Rainy Mountain, 22 from the Bartram Trail site and 17 from the Rainy Mountain Ridge site. All but three were yellow pine trees. The chronology created from yellow pines at Rainy Mountain included 27 individual tree-ring series spanning from 1889 to 2012 that crossdated with an interseries correlation of 0.505. Using this chronology, fire scars from 20 samples were assigned accurate dates. However, this chronology was not long enough to date most of the samples taken from dead stumps, as these ring series were too old to sufficiently overlap with the Rainy Mountain yellow pine chronology. These undated samples were assembled into a floating tree-ring chronology and crossdated against each other. In the event that the Rainy Mountain yellow pine chronology can be extended further back with additional, older tree-ring series, this floating chronology will be useful in dating the fire scars on the older samples.

3.4.2 Fire History

At the Bartram Trail site, seven samples revealed a total of eight fire scars over the period of 1915 to 2012. The earliest recorded fire occurred in 1968 and the most recent in 1991. At the Rainy Mountain Ridge site, 28 fire scars were dated from 13 samples over the period of 1905 to 2012. The earliest recorded fire at this site occurred in 1924 and the most recent in 2010.

The minimum fire intervals ranged from 1 to 2 years between the two sites, while the maximum fire intervals ranged from 6 to 8 years (Table 3.1). Fire intervals were calculated between 1960 and 2012, because nearly all fires found on my samples occurred in this period. The mean fire interval was similar at the two sites, with values of 3.06 years for RMR and 4.60 years for BTR. At BTR, the fire event in 1968 was most widespread and was recorded in three trees (Figure 3.6). At RMR, fires in 1972, 1983, and 1993 were most widespread, with three trees recording fire during each of these years (Figure 3.7). Standard deviation was 2.79 years at BTR and 5.20 years at RMR, and the coefficient of variation was 0.61 at BTR and 1.09 at RMR. The standard deviation and coefficient of variation measure the variation about the mean fire interval. Lower values indicate a more regular fire interval, while higher values indicate more irregular fire intervals over time.

Fire data from the two sites were combined to compare fire history characteristics over the Rainy Mountain area as a whole. All 20 dated fire-scarred samples were included, creating a fire history at Rainy Mountain from 1905 to 2012. In total, 36 fire scars were dated. The combined chronology had a minimum fire interval of one year and a maximum of 20 years (Table 3.1; Figure 3.8). The combined mean fire interval was 3.91 years and the median fire interval 2.8 years. Fire seasonality was also recorded. Between the two sites, 19 scars were recorded in the dormant section of the ring, seven were recorded in the early one-third portion of the earlywood (indicating early growing season fires), four were recorded in the middle portion of the earlywood (indicating fires in the middle of the growing season), and six were indistinct. Undated samples were not included in the fire history, but the number of fire scars were recorded (Table 3.2).

Table 3.1: Fire history statistics for Bartram Trail, Rainy Mountain Ridge, and Rainy Mountain as a whole.

	Total Scarred Samples	MFI	MIN	MAX	SD	CV
Bartram Trail	7	4.60	2.00	8.00	2.79	0.61
Rainy Mountain Ridge	13	3.06	1.00	6.00	1.44	0.47
Rainy Mountain	20	2.45	1.00	6.00	1.43	0.58

MFI, mean fire interval; MIN, minimum fire interval; MAX, maximum fire interval; SD, standard deviation; CV, coefficient of variation. All values are in years except for CV. Statistics calculated from 1960 to 2012 to account for the period of reliability. Most fires occurred in this time

Table 3.2: Total number of fire scars on undated stumps at Rainy Mountain.

Sample ID	Number of Fire Scars
BTR001	1
BTR002 (A and B)	5
BTR003	1
BTR005	2
BTR008	1
BTR020	1
BTR022 (A and B)	7
RMR012	3
Total	21

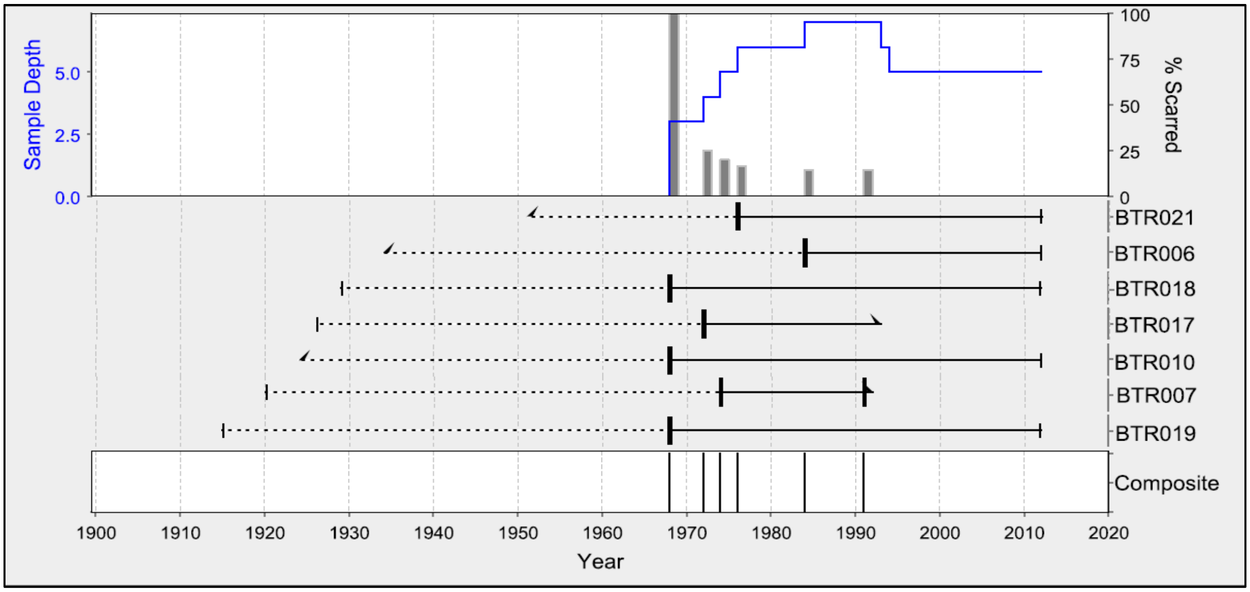

Figure 3.6: Fire history chart showing fires that occurred at the BTR site since 1915. Each stacked horizontal line represents an individual sample. The line is solid during recorder years (after the first fire scar) and dotted in non-recorder years. A solid vertical dash at the oldest and most recent year in the sample indicates the presence of pith and bark, while a diagonal dash indicates pith or bark were absent. Bold vertical dashes along the lines indicate a fire event occurring in the corresponding year. The top graph shows sample depth as the number of recording trees in a year (blue line) and the percentage of trees scarred (gray bars).

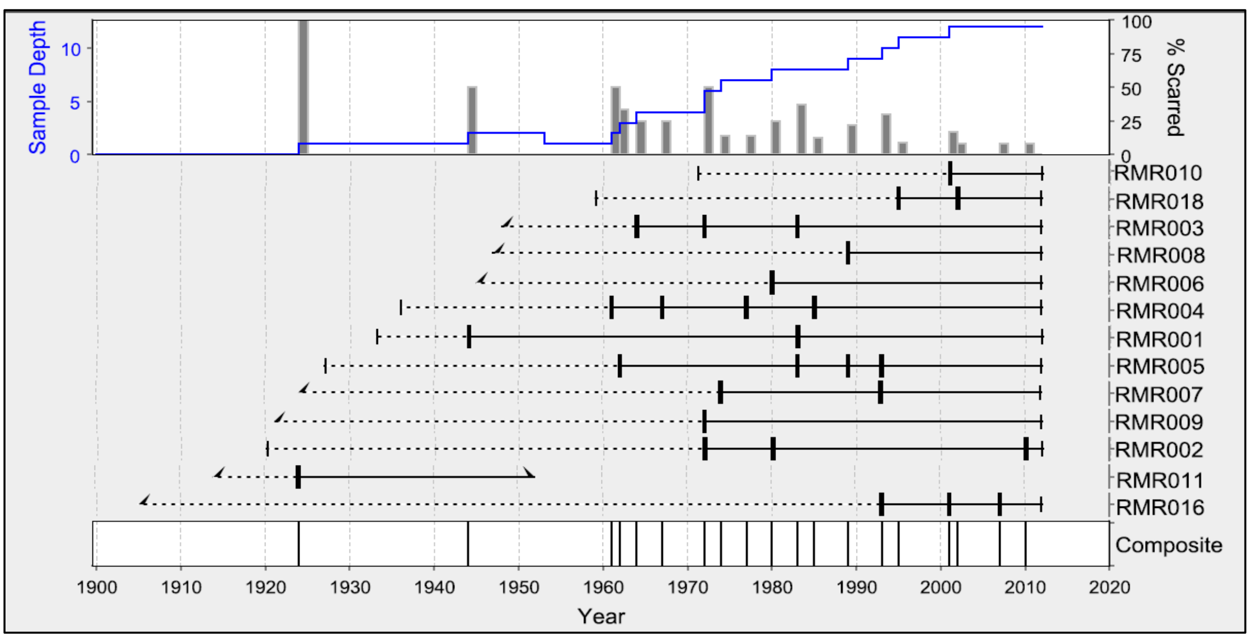

Figure 3.7: Fire history chart showing fires that occurred at the RMR site since 1904. For chart explanation, see Figure 3.6.

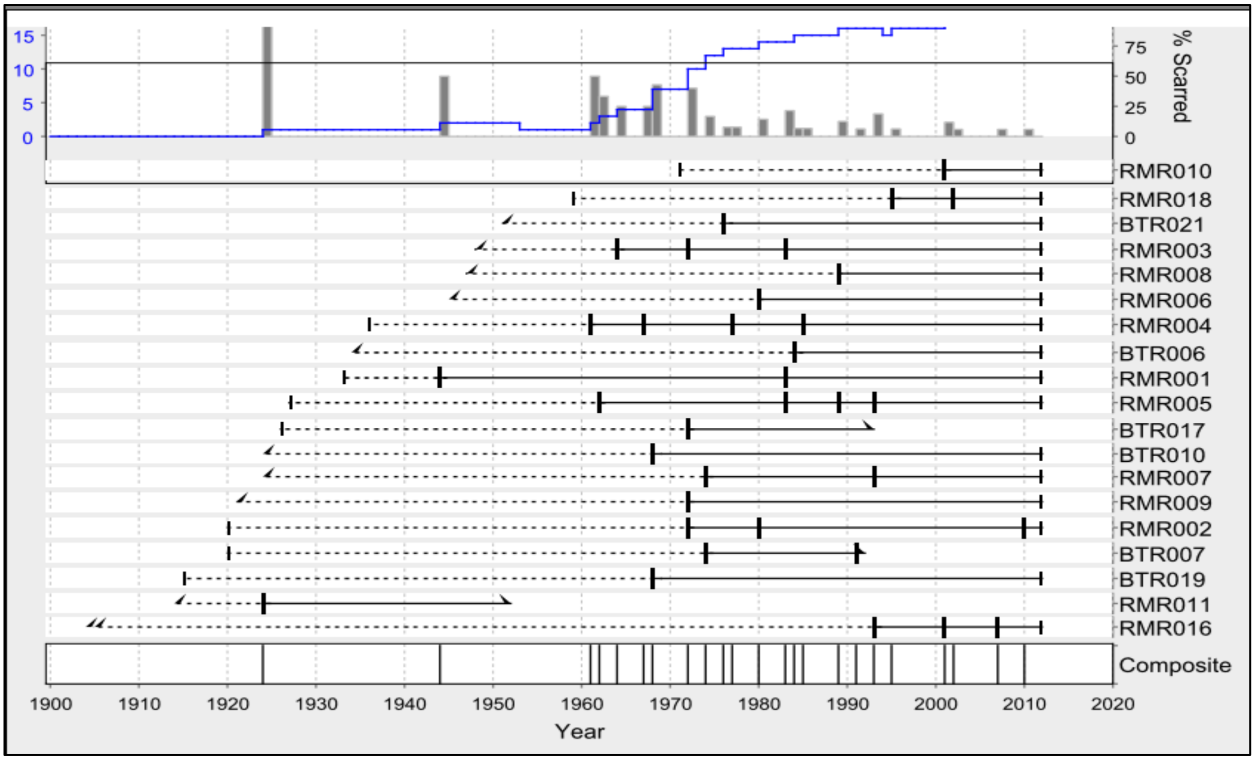

Figure 3.8: Combined fire history chart showing fires that occurred at the BTR and RMR sites. For chart explanation, see Figure 3.6.

3.4.3 Stand Dynamics

Cores were taken from a total of 301 trees to study stand dynamics at Rainy Mountain. Cores from 109 trees at 10 plots were taken from BTR (Figure 3.9), 78 trees from 8 plots at RMR (Figure 3.10), and 111 trees from 12 plots at RMW (Figure 3.11). Stand density was highest at BTR (Table 3.2), with an average of 10.9 trees per 0.01 ha plot, and lowest at RMR, with an average of 9.75 trees per 0.01 ha (Table 3.3). At RMW, stand density was 10.09 trees per plot (Table 3.4). Blackgum had the highest relative density of species type at both BTR and RMW. Pitch pine had the highest relative density at RMR, followed closely by blackgum. At all three sites, red maple also had a high relative density. Pitch pine density was high at both RMR and RMW, but was not as high at BTR.

Measures of relative stand dominance, calculated based on the total basal area in meters of a given species in the plot, favored yellow pines and oaks because of the large size of many of the trees cored of those species. Blackgum had the highest relative stand dominance at BTR, but pitch pine was highest at RMR and RMW. Red maple, while consistently having one of the highest relative densities, had low values of relative dominance at each of the three sites.

At BTR, blackgum had the highest importance value (27.07%), followed by red maple (19.20%), pitch pine (10.19%), and chestnut oak (9.08%). At RMR, pitch pine had the highest importance value (35.94%), followed by blackgum (20.99%) and red maple (12.09%). At RMW, pitch pine had the highest importance value (22.06%), followed by blackgum (21.84%) and red maple (13.89%). For the Rainy Mountain area as a whole, blackgum had the highest relative density, followed by red maple and pitch pine (Table 3.5). Relative dominance and importance values were highest for blackgum, followed by pitch pine and red maple in both cases.

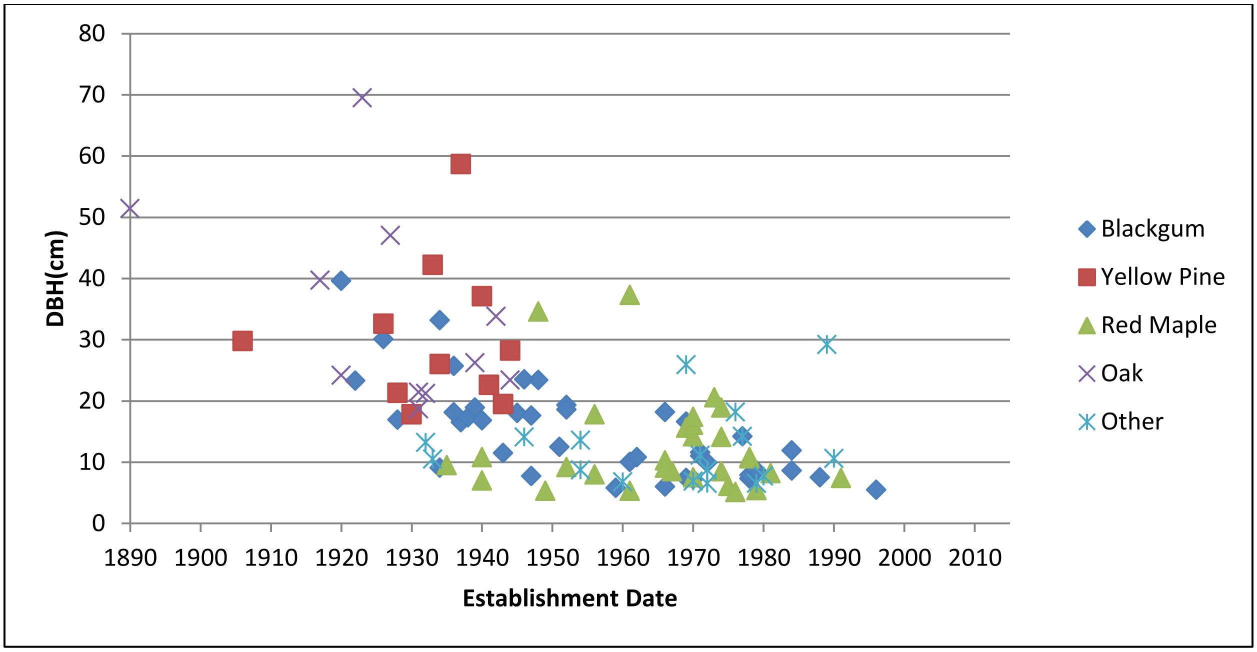

Figure 3.9: Establishment date plotted versus diameter at breast height in 2012 for trees sampled at BTR.

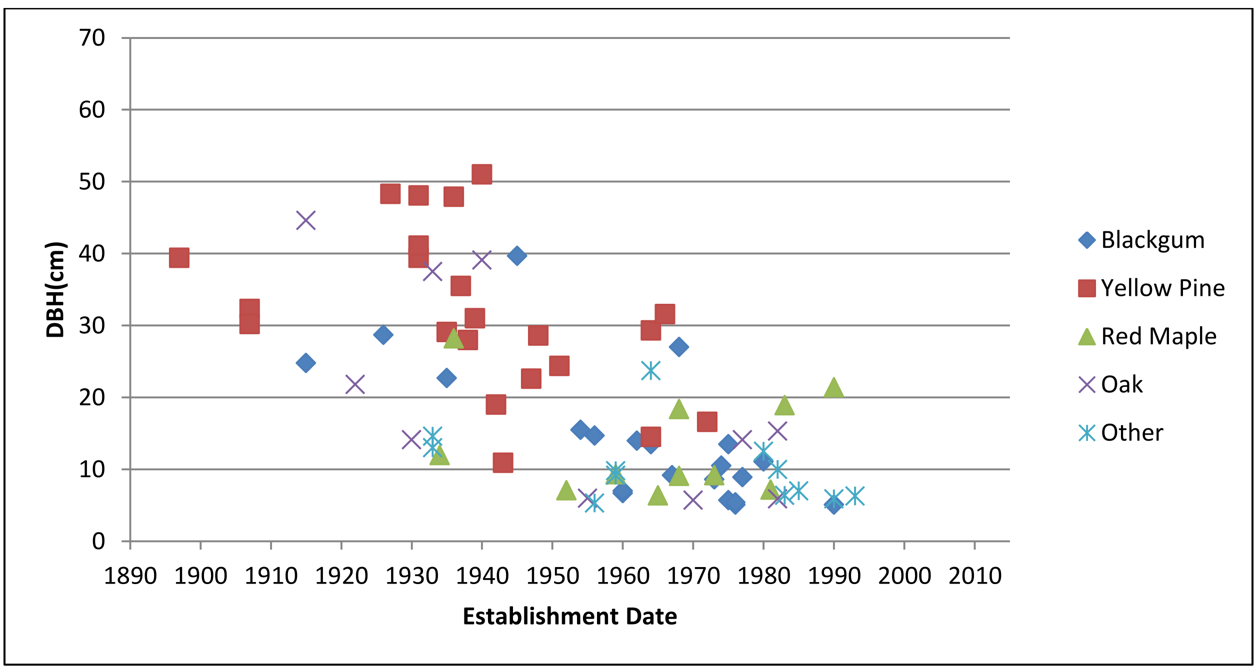

Figure 3.10: Establishment date plotted versus diameter at breast height in 2012 for trees sampled at RMR.

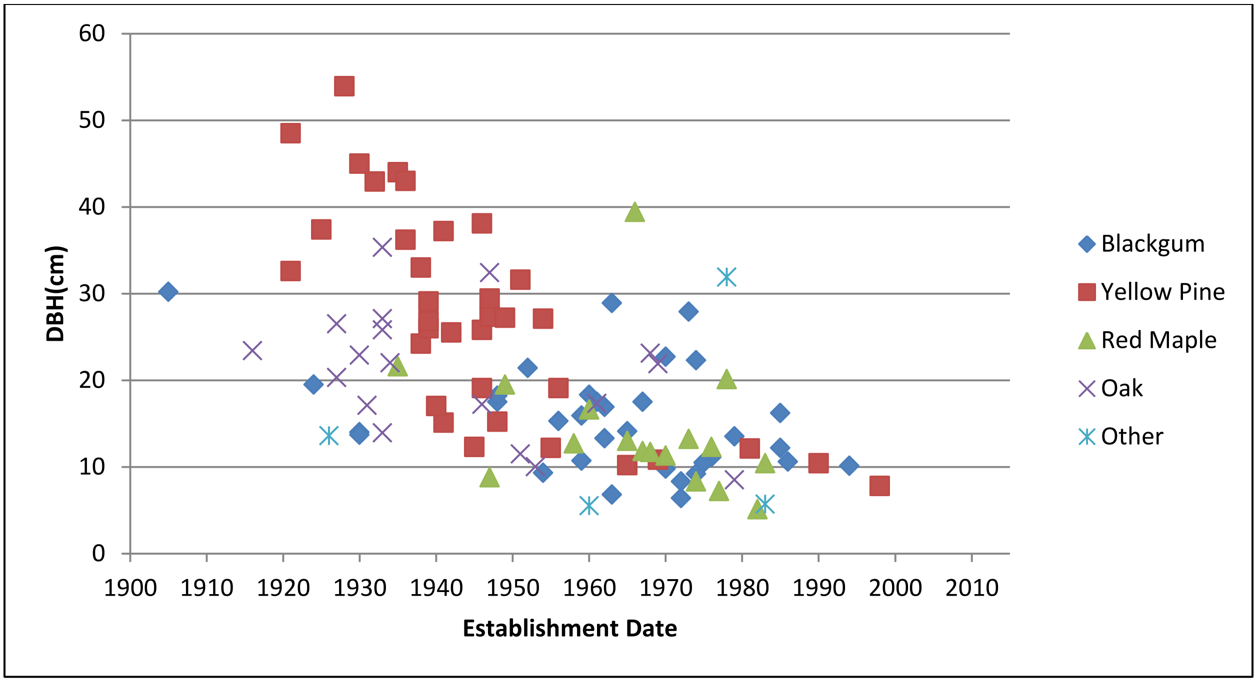

Figure 3.11: Establishment date plotted versus diameter at breast height in 2012 for trees sampled at RMW.

Table 3.3: Forest mensuration values calculated for BTR.

Species	Count	Relative Frequency	Relative Stand Density	Relative Dominance	Importance Value (%)
NYSA	39	23.26	35.78	22.16	27.07
ACRU	27	20.93	24.77	11.89	19.20
PIRI	7	6.98	6.42	17.18	10.19
QUMO	8	4.65	7.34	15.23	9.08
LITU	9	9.30	8.26	5.31	7.62
QURU	2	6.98	1.83	12.54	7.12
CACO	8	11.63	7.34	1.65	6.87
QUCO	3	6.98	2.75	8.58	6.10
PIVI	4	4.65	3.67	5.28	4.53
PIST	2	4.65	1.83	0.17	2.22
ACSA	0	0.00	0.00	0.00	0.00
Total	109	100.00	100.00	100.00	100.00

ACRU (red maple), NYSA (blackgum), QUCO (scarlet oak), QURU (red oak), QUMO (chestnut oak), CACO (bitternut hickory), LITU (tulip-poplar), PIST (white pine), PIRI (pitch pine), PIVI (Virginia pine), PIEC (shortleaf pine), ACSA (sugar maple). Species are listed in order from highest to lowest importance values.

Table 3.4: Forest mensuration values calculated for RMR.

Species	Count	Relative Frequency	Relative Stand Density	Relative Dominance	Importance Value (%)
PIRI	22	17.65	28.21	61.96	35.94
NYSA	21	23.53	26.92	12.51	20.99
ACRU	12	14.71	15.38	6.19	12.09
QURU	7	14.71	8.97	8.09	10.59
CACO	5	8.82	6.41	1.15	5.46
LITU	3	8.82	3.85	0.77	4.48
PIVI	2	2.94	2.56	3.77	3.09
QUCO	1	2.94	1.28	4.34	2.85
PIST	3	2.94	3.85	0.28	2.36
QUMO	2	2.94	2.56	0.94	2.15
ACSA	0	0.00	0.00	0.00	0.00
Total	78	100.00	100.00	100.00	100.00

Species abbreviations as in Table 3.3.

Table 3.5: Forest mensuration values calculated for RMW.

Species	Count	Relative Frequency	Relative Stand Density	Relative Dominance	Importance Value (%)
PIRI	21	15.69	18.92	31.58	22.06
NYSA	34	19.61	30.63	15.29	21.84
ACRU	18	17.65	16.22	7.81	13.89
QUMO	9	13.73	8.11	5.05	8.96
PIVI	8	5.88	7.21	13.30	8.80
PIEC	6	5.88	5.41	12.17	7.82
QUCO	6	7.84	5.41	8.12	7.12
QURU	3	5.88	2.70	2.06	3.55
CACO	4	3.92	3.60	0.98	2.84
ACSA	1	1.96	0.90	1.86	1.57
PIST	1	1.96	0.90	1.77	1.54
Total	111	100.00	100.00	100.00	100.00

Species abbreviations as in Table 3.3.

At BTR, 1,775 seedlings and 174 saplings were counted in 10 plots (Table 3.6). Red maple had the highest count density at the site, with 813 seedlings (relative density of 45.8) and 129 saplings (relative density of 74.14). The red oaks and chestnut oak had a high relative density of seedlings (22.93 for red oaks and 19.72 for chestnut oak), but a low density of saplings. Blackgum, a canopy dominant, had a low relative density of seedlings (16.5), but the second highest relative density of saplings after red maple.

At RMR, 1,210 seedlings and 116 saplings were counted (Table 3.7). Red maple had the highest relative density of seedlings (42.11) and saplings (48.28). Red oaks and tulip-poplar both had high relative densities of seedlings. Again, a substantial amount of the saplings were red maple, followed by blackgum and red oaks. At RMW, 1,004 seedlings and 100 saplings were counted (Table 3.8). Red maple had the highest relative density of seedlings (52.99) and saplings (72.03), with red oak second in both categories (33.86 for seedlings and 10 for saplings). For the Rainy Mountain area as a whole, 3,989 seedlings and 398 saplings were counted over the 30 plots (Table 3.9). Red maple had the highest relative density of seedlings (43.22) and saplings (64.57). Red oaks had the second highest relative density of seedlings (27.9), but blackgum had the second highest relative density of saplings (13.07).

Table 3.6: Forest mensuration values summed across three sites at Rainy Mountain.

Species	**Count**	**Relative Frequency**	**Relative Stand Density**	**Relative Dominance**	**Importance Value (%)**
NYSA	97	21.87	32.23	16.78	23.63
PIRI	50	13.28	16.61	35.74	21.88
ACRU	57	17.97	18.94	8.69	15.20
QUMO	19	7.81	6.31	7.25	7.12
QURU	12	8.59	3.99	7.35	6.64
PIVI	14	4.69	4.65	7.81	5.72
QUCO	10	6.25	3.32	7.16	5.58
CACO	17	7.81	5.65	1.26	4.91
LITU	12	5.47	3.99	2.01	3.82
PIEC	6	2.34	1.99	4.51	2.95
PIST	6	3.12	1.99	0.80	1.97
ACSA	1	0.78	0.33	0.66	0.59
Total	301	100.00	100.00	100.00	100.00

Species abbreviations as in Table 3.3.

Table 3.7: Seedling and sapling survey statistics for BTR.

	Seedlings		**Saplings**	
Species	**Count**	**Relative Density**	**Count**	**Relative Density**
ACRU	813	45.80	129	74.14
NYSA	165	9.30	24	13.79
RED OAK	407	22.93	12	6.90
QUMO	350	19.72	4	2.30
CACO	23	1.30	2	1.15
CAOV	2	0.11	0	0.00
LITU	15	0.85	3	1.72
PIST	0	0.00	0	0.00
PIRI	0	0.00	0	0.00
Total	1775	100.00	174	100.00

Seedlings and saplings from the red oak family (scarlet oak, red oak, and black oak) were all classified as “red oak” because the strong similarity between these three species as seedlings made them difficult to tell apart. Species abbreviations as in Table 3.3.

Table 3.8: Seedling and sapling survey for RMR.

	Seedlings		**Saplings**	
Species	**Count**	**Relative Density**	**Count**	**Relative Density**
ACRU	379	31.32	7.00	48.28
NYSA	68	5.62	2.50	17.24
RED OAK	366	30.25	2.50	17.24
QUMO	43	3.55	0.50	3.45
CACO	40	3.31	0.38	2.59
CAOV	0	0.00	0.00	0.00
LITU	294	24.30	0.75	5.17
PIST	20	1.65	0.88	6.03
PIRI	0	0.00	0.00	0.00
Total	1210	100.00	14.50	100.00

Species abbreviations as in Table 3.3.

Table 3.9: Seedling and sapling survey for RMW.

	Seedlings		**Saplings**	
Species	**Count**	**Relative Density**	**Count**	**Relative Density**
ACRU	532	52.99	72	72.03
NYSA	44	4.38	8	8.00
RED OAK	340	33.86	10	10.00
QUMO	42	4.18	2	2.00
CACO	41	4.08	2	2.00
CAOV	0	0.00	0	0.00
LITU	0	0.00	2	2.00
PIST	5	0.50	3	3.00
PIRI	0	0.00	1	1.00
Total	1004	100.00	100	100.00

Species abbreviations as in Table 3.3.

Table 3.10: Seedling and sapling survey summed across three sites at Rainy Mountain.

	Seedlings		Saplings	
Species	**Count**	**Relative Density**	**Count**	**Relative Density**
ACRU	1724	43.22	257	64.57
NYSA	277	6.94	52	13.07
RED OAK	1113	27.90	42	10.55
QUMO	435	10.90	18	4.52
CACO	104	2.61	7	1.76
CAOV	2	0.05	0	0.00
LITU	309	7.75	11	2.76
PIST	25	0.63	10	2.51
PIRI	0	0.00	1	0.25
Total	3989	100.00	398	100.00

Species abbreviations as in Table 3.3.

3.5 Discussion

3.5.1 Red Maple and Blackgum

At all three sites in the Rainy Mountain study area, forest composition is becoming dominated by red maple and blackgum, species not noted as being dominate in the pine-oak forest type of the southern Appalachians. These findings are consistent with results of similar studies conducted in the southern Appalachians (DeWeese 2007; Feathers 2010; LaForest 2012). Over one-half of all canopy trees sampled on Rainy Mountain were either blackgum or red maple. While blackgum and red maple have high importance values, most trees cored were young with small diameters. Even though blackgum and red maple were more frequent, they did not have the highest calculated levels of dominance because dominance was calculated as a function of total basal area. Although red maple and blackgum are not currently the most dominant species of canopy tree at all Rainy Mountain sites, the large number and relative young age of these trees compared to other older trees indicate that these two tree species are becoming the most common trees in the forest.

Red maples were even more common in seedling and sapling surveys, where they were the most abundant species at all three sites. Red maple is known to be a prolific seeder (Walters and Yawney 1990), but the proportionally high number of red maple seedlings, saplings, and young trees establishing in the forest indicates that current forest conditions are favoring red maple growth over that of other species.

Blackgum was not as common as red maple in the seedling surveys, likely because the species does not reproduce as prolifically as red maple. However, blackgum saplings had one of the highest relative densities of all species, particularly at BTR and RMR, and were second overall only to red maple. This large density of blackgum saplings, as well as the large number of mature trees present, indicates that a large percentage of blackgum seedlings continue to survive and grow into saplings and trees that reach maturity.

3.5.2 Yellow Pine and Red Oak

Species that traditionally dominate southern Appalachian forests, such as those on Rainy Mountain in northern Georgia, are the yellow pines (pitch, Virginia, and shortleaf) and red oaks (red and scarlet). The yellow pines were among the most dominant species at all three sites based on importance values. Of the 301 trees cored at Rainy Mountain, 70 were pitch, Virginia, or shortleaf pine. Pitch pine had the second highest importance value of all tree species. A large portion of the mature forest is composed of yellow pines, and the high importance values calculated are a product of the quantity and size of these trees. Yellow pines were particularly prevalent at the RMR site, comprising over one-third of all trees sampled.

However, yellow pines were virtually nonexistent as seedlings and saplings. Only one pitch pine sapling was discovered at RMW plot 25 and no other pine seedlings were found in the 30 plots. While walking between sampling plots at RMR, another two pitch pine saplings were observed. Given the proliferation of red maples and blackgum and the dearth of young yellow pines, environmental conditions appear to favor red maple/blackgum regeneration and not yellow pine regeneration.

The two red oak species found on Rainy Mountain, northern red oak and scarlet oak, accounted for 22 of the total trees cored. Most of these trees were large, and the two species have a combined importance value of 10.89, a relatively high value for so few trees. Unlike the yellow pines, however, red oaks appear to be regenerating in abundance. Relatively large numbers of red oak seedlings and saplings were counted at all three Rainy Mountain sites. Red oaks had the second highest relative density of seedlings, and the third highest relative density of saplings, behind red maple and blackgum.

3.5.3 Fires at Rainy Mountain

The fire histories constructed from samples at the BTR and RMR sites combined to form a 107-year long history of fire events on Rainy Mountain. Dates were obtained for 36 fire events at Rainy Mountain, eight at BTR and 28 at RMR. Fire as a natural disturbance was very evident at RMR, and fire scars, char, and burned hardwoods were present throughout the site. Fire was less obvious at BTR, but this site was much larger than RMR and the individual fire-scarred samples were spaced farther apart. Many of the fire-scarred samples collected at BTR were from old logged stumps and could not be dated. As a result, BTR only has a sample depth of eight fire scars. All but four of the scarred samples collected from RMR were from living trees, resulting in 26 dated fire scars. Thus, the RMR fire history is much more extensive than that of BTR.

While the RMR and BTR sites showed ample evidence of fire, no signs of fire were observed at RMW. The RMW site is more frequently visited, so perhaps this area was more frequently monitored and fires were prevented or were quickly suppressed. The trail leading up to Rainy Mountain through RMW begins at Warwoman Dell, a highly used picnic area, and Rainy Mountain Boy Scout Camp borders the southern edge of the site. Multiple four-wheel drive roads with fresh tracks and garbage cross the site, and a well-marked historical cemetery and scenic overlook attract visitors to hike the trail up through the site.

On samples analyzed from BTR and RMR, seasonality of fire occurrence was recorded when possible on each fire scar. Fires in the southern Appalachians are ignited either by lightning or humans, and the season in which the fire occurs can help assess the ignition source. Anthropogenic fires are more likely to occur in the dormant and early growing season of a tree (winter and spring), while lightning-induced fires occur in summer (Lafon et al. 2005). Most samples analyzed at Rainy Mountain had fire scars in the dormant season portion of the ring, indicating spring fires of anthropogenic origin.

The results of the stand dynamics study at Rainy Mountain clearly show that species composition is in the process of changing from a pine-oak dominated forest to a red maple-blackgum dominated forest. At other sites in the southern Appalachians, a composition shift of this type has been linked to fire suppression (Lafon and Grissino-Mayer 2007; Aldrich et al. 2010; LaForest 2012). With the current limitations of the Rainy Mountain fire history, it is difficult to conclude whether fire suppression is the leading cause of shifting forest composition at this location. Most of the Rainy Mountain fires occurred after 1960, apparently contradicting the hypothesis that the lack of fires in eastern forests is a main factor driving changes in forest composition. In the last 50 years, fires at Rainy Mountain have occurred frequently. The BTR and RMR sites had mean fire intervals of 4.60 and 4.78 years respectively. This pattern of a relatively high fire frequency is most likely explained through instances of human interference, such as arson. Unfortunately, this study was limited by a scarcity of older trees and stumps in the Rainy Mountain area that could have been used to piece together the pre-1900 fire history of the site.

Future research into the fire history on Rainy Mountain would benefit from an extensive effort to identify more old living yellow pine trees (100 years old or more) and stumps. An adequate number of old samples will provide a yellow pine tree-ring chronology long enough to accurately date the fire scars on the stump samples. These dates could then extend the fire history well into the 1800s. A detailed scouting operation of Rainy Mountain would very likely discover these trees, as well as additional logged stumps with old fire scars.

3.5.4 Human Influence on Fire Activity and Forest Composition

The high frequency of recent fires at Rainy Mountain, coupled with a decline in the pine-oak forest type, does not agree with evidence found at other southern Appalachian Mountain sites that link the decline with fire suppression (DeWeese 2007; Feathers 2010; LaForest 2012). However, fire frequency alone may not be sufficient to consistently spur pine regeneration. The necessity of less frequent, higher intensity/severity fires for successful establishment of yellow pines in the southern Appalachians has been shown by several studies using controlled burns (Brose and Waldrop 1999; Elliott et al. 1999; Welch et al. 2000; Waldrop et al. 2003). Fires that did burn at Rainy Mountain, though frequent, likely have not been sufficiently intense or severe to encourage continued propagation of yellow pines. Fires of sufficient intensity (a measure of total heat generated by the fire) may be needed to open serotinous pine cones, while the level of fire severity (extent to which the fire affects the forest, such as tree mortality or soil damage) can determine whether canopy trees are killed in the fire or the extent to which the understory has been burned. In the southern Appalachians, studies have shown that yellow pine regeneration depends on fires that are (1) intense enough to open seed cones, (2) sufficiently severe to kill some fire-intolerant canopy species and shrub understory plants, and (3) not so severe as to destroy most of the canopy and render the soil unable of supporting germination (Brose and Waldrop 1999; Waldrop et al. 2003). Yellow pines at Rainy Mountain are not regenerating, although fires have been occurring fairly frequently. This pattern of frequent fires, coupled with reduced yellow pine regeneration, appears to confirm the necessity of moderate to high intensity/severity fires for pine regeneration discussed in previous studies (Brose and Waldrop 1999; Elliott et al. 1999; Welch et al. 2000; Waldrop and Brose 2003; Brose and Waldrop 2006) and shows that knowledge of fire frequency alone is not sufficient when managing to encourage yellow pine regeneration.

A similar pattern of high frequency, low intensity fires was observed by Bratton and Meier (1998) in a nearby study of the Chattooga River watershed. Compiling public records of past fire events, they found a decrease in size and intensity of fires after 1913, but a continued regime of small, frequent fires thereafter. Between 1950 and 1994, they found an average of approximately four fires per 100,000 ha of public land per year that were attributed to lightning strikes or arson/accidental human ignition, each usually no larger than 50 ha. The frequency of fire events increased drastically after World War II until the late 1970s, which the authors linked to repeated acts of arson by locals incited by ongoing political arguments over federal involvement in conservation practices, road closures, designation of wilderness areas, and expansion of protected forest areas, in addition to regular lightning fires.

The increased fire activity between 1950 and 1980 shown by Bratton and Meier (1998) is similar to the dendrochronological fire history constructed at Rainy Mountain. The Rainy Mountain chronology extends from 1904 to 2012, but 65% of all fire scars were dated to between 1960 and 1990. Given the close proximity of Rainy Mountain to the study site of Bratton and Meier (1998), the elevated fire activity between 1960 and 1990 at Rainy Mountain may also be a result of increased arson during this period. In light of fire suppression and active USFS management of forest fires, fires ignited as a result of arson and lightning strikes, though frequent, were likely to have been contained quickly and to have remained small and localized.

Small, localized, and possibly low-severity fires of this type are not capable of the widespread and more severe/intense burning necessary to propagate the pine-oak forest type. Although the Rainy Mountain fire chronology does not extend prior to 1904, historical accounts indicate the occurrence of large, widespread fires in the Southeast in association with early human settlement patterns. The noted naturalist and explorer William Bartram mentioned in several accounts witnessing what appeared to be natural- and Native American-induced fires during his travels through areas of northern Georgia and southwestern North Carolina (Harper 1980), as did the Spanish conquistador Hernando de Soto (Sheppard 2001). The prominent surveyor Andrew Ellicott also noted large fires near the Chattooga River in Georgia and South Carolina started by early European settlers (Mathews 1908). In fact, Native American burning of the southeastern forests prior to European settlement is believed to have been partly responsible for the forest composition observed by settlers in the 18th and 19th centuries (Hudson 1976). As the Industrial Revolution took hold and Europeans began settling the southeast in larger and larger numbers, expansive segments of forests were burned and cleared for agriculture, timber harvest, and resource extraction (Williams 1989; Silver 1990). These fires were widespread and frequent, and they were left to burn unabated since forested land was not under federal supervision at this time.

Fires instigated by Native Americans and early settlers possibly contributed to the survival of the pine-oak forest in the southern Appalachian Mountains. However, once settlement patterns and resource extraction techniques changed, and much of the forested land passed under federal management, the nature of human-induced fires also changed. Fires started by humans were reduced to isolated acts of arson and accidents, and the extent of individual fire events were kept in check by organized fire suppression efforts. Similarly, the naturally ignited fires that occurred were put out quickly or died before growing to a sufficient severity and intensity to disturb a significant area of forest. Fires still do occur in the CONF, as is illustrated by the fire history developed at Rainy Mountain, but a change in human management practices and involvement in the natural landscape has altered the characteristics of these fires. As a result, fires within the last 100 years in the CONF tend to be small, localized events that are not sufficiently severe to disturb the forest in a way that facilitates continued propagation of the pine-oak forest type.

CHAPTER FOUR

4. SUMMARY AND CONCLUSIONS

4.1 Have the stand structure and forest composition changed over the last several decades in the Chattahoochee National Forest?

The canopy of pine-oak forests of the southern Appalachian Mountains is composed of predominantly yellow pine, oak, and hickory trees. In a completely natural environment, one would expect the forest to maintain this composition into the future. However, evidence from Rainy Mountain clearly shows that yellow pine trees are not reproducing and establishing at a level that will allow those species to remain dominate in the forest.

Currently, the forest at Rainy Mountain remains dominated by yellow pines and oaks, but the majority of trees are more than 60 years old and very few young trees, seedlings, and saplings are present. Trees with establishment dates from 1950 to the present are almost exclusively species not considered to dominate pine-oak forests, namely red maple and blackgum. This suggests that, prior to 60 years ago, the forest was composed of mostly yellow pines and red oaks, with fewer blackgums, tulip-poplars, and hickories, and almost no red maples. Since about the 1950s, the forest composition has changed in favor of red maple and blackgum, with hickory, tulip-poplar, and chestnut oak in lesser quantities. A quick walk around Rainy Mountain unveils a forest composed mostly of widely spaced mid-sized to large yellow pines and red oak with a high density of small to mid-sized red maple and blackgum. The lower reaches of the forest are covered in dense clumps of mountain laurel and red maple saplings, and the forest floor is covered in a thick duff layer of deciduous leaves and dead pine trees.

One of the main goals of this research was to document the changing forest composition in the southern Appalachian forest on Rainy Mountain. Similar regional studies have provided evidence of shifting stand structure, and the results from this study confirm and strengthen this evidence. However, this study was not conducted simply to confirm results from other studies, but to contribute to a growing body of knowledge of forest change in the southern Appalachians, ideally allowing for the results to be applied at a broader scale. The results from this study contribute to evidence produced from a growing network of regional sites to show that modern forests are experiencing a shift from yellow pine-oak dominance to red maple-blackgum dominance. This phenomenon should be recognized as a significant area of concern for forest managers and conservationists.

4.2 Based on the past and present composition, dynamics, and structure of the current forest, which species will be dominant in the Chattahoochee National Forest in the future?

The study of stand dynamics and forest composition at Rainy Mountain was conducted with the intent of providing forest managers and conservationists with information on the projected composition of their local forests in the future. This information is essential for developing plans for effective management and increasing the understanding that natural and human processes are influencing modern forests. This study contributed to strengthening the knowledge base regarding stand dynamics in northern Georgia, and it will give forest personnel some much needed information on the future composition of their forests.

The forest composition, dynamics, and structure of the Rainy Mountain forest are changing. This study of stand dynamics showed that 60 to 100 years ago, the forest included mainly yellow pines and red oak trees. But, over the last 50 years, yellow pine establishment has been replaced by red maple and blackgum establishment. Most of these red maple and blackgum trees are between 15 and 50 years old. Without competition from similar age-classed yellow pines, these young trees will grow into the next class of dominate tree individuals. Additionally, a forest floor covered in red maple and blackgum seedlings and saplings indicate that the development of a hardwood-dominated forest will continue well into the future. The near total absence of yellow pine seedlings and saplings indicates that yellow pines are on the decline. With no young trees growing in as replacements, yellow pines will likely be an inconsequential component of the forest after the current class of mature trees dies off.

While yellow pines are struggling to maintain dominance at Rainy Mountain, red oaks and hickories are still germinating and establishing. Red oaks were very prominent in the seedling and sapling surveys, and several of the red oak saplings were large and healthy. Hickories, mainly bitternut and pignut, were not as common as red oaks in the seedling and sapling counts. But, several young individual hickory trees were among those cored at Rainy Mountain, indicating that hickories are also successfully establishing. To a lesser extent, chestnut oak, white pine, and tulip-poplar were also observed in the seedling and sapling survey and several young trees of those species were cored.

The future composition of the forest at Rainy Mountain will be dominated by red maple and blackgum. Red oaks, hickories, chestnut oaks, white pine, and tulip-poplar will also be present in the forest canopy, but to a lesser extent. Yellow pines are failing to reestablish, and will no longer be a dominant member of the forest canopy after the currently living individuals die. The high density of mountain laurel suggests that this shrub species is becoming a permanent member of the understory and will likely influence the density and size of incoming trees with canopy potential. Increased mountain laurel density is likely a product of decreased fire activity associated with the onset of fire suppression, as was shown in southwestern Virginia by DeWeese (2007) and Aldrich et al. (2010). Fires would increase mountain laurel mortality, but a lack of fire allows these understory shrubs to grow large and dense.

4.3 How often have fires occurred in the recent past at Rainy Mountain and what implications does the occurrence or lack of occurrence of fires have for the stand dynamics, structure, and composition in the forest?

In addition to studying stand dynamics of the Rainy Mountain forest, another major goal of this research was to develop a fire history for northern Georgia. Thirty-six fire scars from 20 samples were successfully dated, resulting in a fire history spanning from 1904 to 2012. Fires have occurred relatively frequently over this time period. The fire history was constructed almost exclusively from samples taken from living trees; a number of scarred samples were also obtained from stumps but could not be dated because of the lack of a sufficiently long reference tree-ring chronology.

This study was successful in determining how often fires have occurred over the last 108 years. As only one previous dendrochronological fire history has been constructed in the Chattahoochee (Brose and Waldrop 2006), this is important information for forest managers looking to understand the role fires play in their forests. The results confirm that fires have been occurring over the last 108 years, and the forest is continuing to burn, even as recently as 2010. Unfortunately, the inability to date most of the non-living samples made it impossible to extend the history back any further than 1904. Without this information, it is difficult to answer the question of whether a lack of fires or fire suppression influenced the changing composition of the Rainy Mountain forest. Fire suppression efforts would have begun in the 1930s when the USFS assumed control of the property. Evidence supporting a shift in forest composition coincident with changing fire characteristics would require a fire history that extends much further into the past to attain a complete picture of changing fire patterns.

However, though the Rainy Mountain fire history showed a high frequency of fires, most of these fires occurred between 1960 and 1990. Bratton and Meier (1998) found a similar spike in fire frequency at nearby sites resulting from increased arson activity by locals in response to frustrations with federal management practices of national forest lands. It is possible that Rainy Mountain parallels this same increase in human-induced fires in the mid-20th century. Anthropogenic fires ignited by arson or accident, as well as occasional fires started by lightning, would be localized and readily extinguished by National Forest fire managers.

Although fires are more frequent than expected at Rainy Mountain, yellow pines are still failing to regenerate and the forest is shifting to one dominated by red maple and blackgum. But, a high frequency of low-severity fires alone may not facilitate yellow pine regeneration, as yellow pines require moderate-severity to high-severity fires to burn the duff layer, remove fire-intolerant competitors, and open seed cones. Most Rainy Mountain fires observed in the recent fire history have been small and localized, not reaching the required severity to encourage continued pine regeneration. Prescribed burning efforts in national forest land have tried to replicate the required moderate to high-severity fires for pine regeneration, but without regular fire activity, yellow pines will cease to exist in the southern Appalachians.

REFERENCES

Abella, S.R. and V.B. Shelburne. 2003. Eastern white pine establishment in the oak landscape of the Ellicott Rock Wilderness, southern Appalachian Mountains. *Castanea* 68: 201–210.

Abrams, M.D., D.A. Orwig, and T.E. Demeo. 1995. Dendroecological analysis of successional dynamics for a presettlement-origin white pine-mixed oak forest in the southern Appalachians, U.S.A. *Journal of Ecology* 83(1): 123–133.

Abrams, M.D., and G.J. Nowacki. 1992. Historical variation in fire, oak recruitment, and post-logging accelerated successions in central Pennsylvania. *Bulletin of the Torrey Botanical Club* 119(1): 19–28.

Abrams, M.D. 1992. Fire and the development of oak forests. *BioScience* 42(5): 346–353.

Aldrich, S.R., C.W. Lafon, H.D. Grissino-Mayer, G.G. DeWeese, and J.A. Hoss. 2010. Three centuries of fire in montane pine-oak stands on a temperate forest landscape. *Applied Vegetation Science* 13: 36–46.

Armbrister, M.R. 2002. Changes in fire regimes and the successional status of Table Mountain pine (*Pinus pungens* Lamb.) in the southern Appalachians, USA. Master's Thesis, University of Tennessee, Knoxville. 151 pp.

Arno, S.F., and K.M. Sneck. 1977. *A Method for Determining Fire History in Coniferous Forests of the Mountain West*. USDA Forest Service General Technical Report INT-42, Intermountain Forest and Range Experiment Station, Ogden, Utah.

Ashe, W.W. 1895. Forest fires: their destructive work, causes, and prevention. Bulletin No. 7, North Carolina Geological Survey, Raleigh, North Carolina.

Ashe, W.W. 1918. Ice storms of the southern Appalachians. *Monthly Weather Review* 46: 374.

Baisan, C.H., and T.W. Swetnam 1990. Fire history on a desert mountain range: Rincon Mountain Wilderness, USA. *Canadian Journal of Forest Research* 20: 1559–1569.

Barden, L.S. 1979. Serotiny and seed viability of *Pinus pungens* in the southern Appalachian Mountains. *Castanea* 44: 44–47.

Barden, L.S. and F.W. Woods. 1973. Characteristics of lightning fires in southern Appalachian forests. *Proceedings of the Annual Tall Timbers Fire Ecology Conference* 13: 345–361.

Barden, L.S., and F.W. Woods. 1976. Effects of fire on pine and pine-hardwood forests in the southern Appalachians. *Forest Science* 22(4): 399–403.

Bogucki, D.J. 1976. Debris slides in the Mt. Le Conte area, Great Smoky Mountains National Park, USA. *Physical Geography* 58(3): 179-191.

Bormann, F.H., and G.E. Likens. 1979. *Pattern and Process in a Forested Ecosystem*. Springer-Verlag: New York.

Braun, E.L. 1950. *Deciduous Forests of Eastern North America*. The Free Press: New York. 596 pp.

Bratton, S.P., and A.J. Meier. 1998. The recent vegetation disturbance history of Chattooga River Watershed. *Castanea* 63(3): 372–381.

Brose, P.H., T. Schuler, D. Van Lear, and J. Berst. 2001. Bringing fire back: the changing regimes of the Appalachian mixed-oak forests. *Journal of Forestry* 99(11): 30–35.

Brose, P.H., and T.A. Waldrop. 2006. Fire and the origin of Table Mountain pine-pitch pine communities in the southern Appalachian Mountains, USA. *Canadian Journal of Forest Research* 36: 710–718.

Brose, P.H., and T.A. Waldrop. 2010. A dendrochronological analysis of a disturbance-succession model for oak-pine forests of the Appalachian Mountains, USA. *Canadian Journal of Forest Research* 40: 1373–1385.

Brose, P.H., F. Tainter, and T.A. Waldrop. 2002. Regeneration history of three Table Mountain pine/pitch pine stands in northern Georgia. *In*: Proceedings of the Eleventh Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. pp. 296–301.

Carlson, P.J. 1995. An assessment of the old-growth forest resource on national forest system lands in the Chattooga River watershed. Chattooga Ecosystem Demonstration Management Project, USDA Forest Service, Franklin, North Carolina.

Chapman, J., P.A. Delcourt, P.A. Cridlebaugh, A.B. Shea, and H.R. Delcourt. 1982. Man-land interaction: 10,000 years of American Indian impact on native ecosystems in the lower Little Tennessee River Valley, eastern Tennessee. *Southeastern Archaeology* 1(2): 115–121.

Christensen, N.L., A.M. Bartuska, J.H. Brown, S. Carpenter, C. D'Antonio, R. Francis, J.F. Franklin, J.A. Macmahon, R.F. Noss, and D.J. Parsons. 1996. The report of the Ecological

Society of America committee of the scientific basis for ecosystem management. *Ecological Applications* 6(3): 665–691.

Clebsch, E.C., and R.T. Busing. 1989. Secondary succession, gap dynamics, and community structure in a southern Appalachian cove forest. *Ecology* 70(3): 728–735.

Clements, F.E. 1916. *Plant Succession: An Analysis of the Development of Vegetation*. Carnegie Institute: Washington, D.C. 512 pp.

Cowell, C.M. 1995. Presettlement Piedmont forests: patterns of composition and disturbance in central Georgia. *Annals of the Association of American Geographers* 85(1): 65–83.

Delcourt, P.A., and H.R. Delcourt. 1998. The influence of prehistoric human-set fires on oak-chestnut forests in the southern Appalachians. *Castanea* 63(3): 337–345.

DeWeese, G. G. 2007. Past fire regimes of Table Mountain pine (*Pinus pungens* Lamb.) stands in the central Appalachian Mountains, Virginia, U.S.A. Doctoral dissertation, University of Tennessee, Knoxville. 322 pp.

Dumas, S., H.S. Neufeld, and M.C. Fisk. 2007. Fire in a thermic oak-pine forest in Linville Gorge Wilderness Area, North Carolina: Importance of the shrub layer to ecosystem response. *Castanea* 72(2): 92–104.

Egler, F.E. 1954. Vegetation science concepts: I. Initial floristic composition: A factor in old-field vegetation development. *Vegetatio* 4: 412–417.

Elliott, K.J., R.L. Hendrick, A.E. Major, J.M Vose, and W.T. Swank. 1999. Vegetation dynamics after a prescribed fire in the southern Appalachians. *Forest Ecology and Management* 114: 199–213.

Feathers, I.C. 2010. Fire history from dendrochronological analyses at two sites near Cades Cove, Great Smoky Mountains National Park, U.S.A. Master's thesis, University of Tennessee, Knoxville. 147 pp.

Foster, D.R. 2000. From bobolinks to bears: interjecting geographical history into ecological studies, environmental interpretation, and conservation planning. *Journal of Biogeography* 27: 27–30.

Fowler, C., and Konopik, E. 2007. The history of fire in the southern United States. *Human Ecology Review* 14(2): 165–176.

Fritts, H.C. 1976. *Tree Rings and Climate.* Academic Press, New York. 576 pp.

Gramley, M. 2005. Fire in the South: A Report by the Southern Group of State Foresters. Winder, Georgia. Online at http://www.dof.virginia.gov/fire/resources/pub-SGSF-Fire-In-The-South.pdf. Accessed 3 October 2012.

Greene, S.W. 1931. The forest the fire made. *American Forests* 53–54.

Grissino-Mayer, H.D. 1999. Modeling fire interval data from the American Southwest with the Weibull distribution. *International Journal of Wildland Fire* 9(1): 37–50.

Grissino-Mayer, H.D. 2001. FHX2–software for analyzing temporal and spatial patterns in fire regimes from tree rings. *Tree-Ring Research* 57(1): 115–124.

Grissino-Mayer, H.D., W.H. Romme, M.L. Floyd, and D.D. Hanna. 2004. Climatic and human influences on fire regimes of the southern San Juan Mountains, Colorado, USA. *Ecology* 85(6): 1708–1724.

Gutsell, S.L., and E.A. Johnson. 1996. How fire scars are formed: coupling a disturbance process to its ecological effect. *Canadian Journal of Forest Research* 26: 166–174.

Gutsell, S.L., and E.A. Johnson. 2002. Accurately ageing trees and examining their height-growth rates: implications for interpreting forest dynamics. *Journal of Ecology* 90: 153–166.

Guyette, R.P., and M.A. Spetich. 2003. Fire history of oak-pine forests in the Lower Boston Mountains, Arkansas, USA. *Forest Ecology and Management* 180: 463–474.

Guyette, R.P., M.A. Spetich, and M.C. Stambaugh. 2006. Historic fire regime dynamics and forcing factors in the Boston Mountains, Arkansas, USA. *Forest Ecology and Management* 234: 293–304.

Harmon, M.E.1982. Fire history of the westernmost portion of Great Smoky Mountains National Park. *Bulletin of the Torrey Botanical Club* 109: 74–79.

Harper, F., ed. 1998. *The Travels of William Bartram.* University of Georgia Press: Athens. 727 pp.

Harrod, J.C., P.S. White, and M.E. Harmon. 1998. Changes in xeric forests in western Great Smoky Mountains National Park, 1936–1995. *Castanea* 63(3): 346–360.

Harrod, J.C., M.E. Harmon, and P.S. White. 2000. Post fire succession and 20th century reduction in fire frequency on xeric southern Appalachian sites. *Journal of Vegetation Science* 11(4): 465–472.

Henderson, J.P. 2006. Dendroclimatological analysis and fire history of longleaf pine (*Pinus palustris* Mill.) in the Atlantic and Gulf coastal plain. Doctoral dissertation, University of Tennessee, Knoxville. 485 pp.

Hessl, A.E., T. Saladyga, T. Schuler, P. Clark, and J. Wixom. 2011. Fire history from three species on a central Appalachian ridgetop. *Canadian Journal of Forest Research* 41: 2031–2039.

Hoss, J.A., C.W. Lafon, H.D. Grissino-Mayer, S.R. Aldrich, and G.G. DeWeese. 2008. Fire history of a temperate forest with an endemic fire-dependent herb. *Physical Geography* 29(5): 424–441.

Hudson, C. 1976. *The Southeastern Indians*. University of Tennessee Press: Knoxville. 573 pp.

Huffman, J.M., W.J. Platt, H.D. Grissino-Mayer, and C.J. Boyce. 2004. Fire history of a barrier island slash pine (*Pinus elliottii*) savanna. *Natural Areas Journal* 24(3): 258–268.

Knebel, L. and T.R. Wentworth. 2007. Influence of fire and southern pine beetle on pine-dominated forests in the Linville Gorge Wilderness, North Carolina. *Castanea* 72(4): 214–225.

Lachmund, H.G. 1921. Some phases in the formation of fire scars. *Journal of Forestry* 19: 638–640.

Lafon, C.W., and J.H. Speer. 2002. Using dendrochronology to identify major ice storm events in oak forests of southwestern Virginia. *Climate Research* 20: 41–54.

Lafon, C.W., and M.J. Kutac. 2003. Effects of ice storms, southern pine beetle infestation, and fire on Table Mountain pine forests of southwestern Virginia. *Physical Geography* 24(6): 502–519.

Lafon, C.W., J.A. Hoss, and H.D. Grissino-Mayer. 2005. The contemporary fire regime of the central Appalachian Mountains and its relation to climate. *Physical Geography* 26(2): 126–146.

Lafon, C.W., and H.D. Grissino-Mayer. 2007. Spatial patterns of fire occurrence in the central Appalachian Mountains and implications for wildland fire management. *Physical Geography* 28: 1–20.

LaForest, L.B. 2012. Fire regimes in lower-elevation forests of Great Smoky Mountains National Park, Tennessee, U.S.A. Doctoral dissertation, University of Tennessee, Knoxville. 291 pp.

Leopold, A. 1924. Grass, brush, timber, and fire in southern Arizona. *Journal of Forestry* 22(6): 1–10.

Lorimer, C.G. 1980. Age structure and disturbance history of a southern Appalachian virgin forest. *Ecology* 58: 139–148.

Lorimer, C.G., and L.E. Frelich. 1989. A method for estimating canopy disturbance frequency and intensity in dense temperate forests. *Canadian Journal of Forest Research* 19: 651–663.

Lynch, C., and A. Hessl. 2010. Climatic controls on historical wildfires in West Virginia, 1939–2008. *Physical Geography* 31: 254–269.

MacCleery, D. 1992. American forests: a history of resiliency and recovery. General Technical Report FS-540, USDA Forest Service and Forest History Society, Durham, North Carolina.

Madany, M.H., T.W. Swetnam, and N.E. West. 1982. Comparison of two approaches for determining fire dates from tree scars. *Forest Science* 28: 856–861.

Mathews, C.V.C. 1908. *Andrew Ellicott, His Life and Letters*. Grafton Press: New York. 256 pp.

Matthews, R.W. and Mackie, E.D. 2007. *Forest Mensuration: A Handbook for Practitioners*. Edinburgh: Forestry Commission. 330 pp.

McCarthy, B.C., C.J. Small, and D.L. Rubino. 2001. Composition, structure, and dynamics of Dysart Woods, an old-growth mixed mesophytic forest of southeastern Ohio. *Forest Ecology and Management* 140: 193–213.

McDonald, R.I., R.K. Peet, and D.L. Urban. 2003. Spatial patterns of *Quercus* regeneration limitation and *Acer rubrum* invasion in a Piedmont forest. *Journal of Vegetation Science* 14(3): 441–450.

Miller, J.D., H.D. Stafford, M. Crimmins, and A.E. Thode. 2009. Quantitative evidence for increasing forest fire severity in the Sierra Nevada and southern Cascade Mountains, California and Nevada, USA. *Ecosystems* 12: 16–32.

Mitchener, L.J., and A.J. Parker. 2005. Climate, lightning, and wildfire in the national forests of the southeastern United States: 1989–1998. *Physical Geography* 26(2): 147–162.

Mann, D.H., F.B. Engstrom, and J.L. Bubier. 1994. Fire history and tree recruitment in an uncut New England forest. *Quaternary Research* 42: 206–215.

Oliver, C.D., and B.C. Larson. 1976. *Forest Stand Dynamics.* John Wiley & Sons, Inc.: New York. 520 pp.

Oosting, H.J. 1956. *The Study of Plant Communities*. W.H. Freeman: San Francisco. 440 pp.

Orvis, K.H., and H.D. Grissino-Mayer. 2002. Standardizing the reporting of abrasive papers used to surface tree-ring samples. *Tree-Ring Research* 58: 47–50.

Peet, R.K., and N.L. Christensen. 1987. Competition and tree death. *BioScience* 37(8): 586–595.

Phillips, D.L., and D.J. Shure. 1990. Patch-size effects on early succession in southern Appalachian forests. *Ecology* 71: 204–212.

Pyne, S.J. 1982. *Fire in America: A Cultural History of Wildland and Rural Fire*. Princeton University Press: Princeton, New Jersey. 654 pp.

Reilly, M.J., M.C. Wimberly, and C.L. Newell. 2006. Wildfire effects on plant species richness at multiple spatial scales in forest communities of the southern Appalachians. *Journal of Ecology* 94: 118–130.

Richardson, D.M. Ed. 1998. *Ecology and Biogeography of Pinus*. Cambridge University Press: Cambridge, United Kingdom. 527 pp.

Robertson, P.A., and A.L. Heikens. 1994. Fire frequency in oak-hickory forests of southern Illinois. *Castanea* 286-291.

Runkle, J.R. 1990. Gap dynamics in an Ohio *Acer-Fagus* forest and speculations on the geography of disturbance. *Canadian Journal of Forest Research* 20: 632–641.

Runkle, J.R., and T.C. Yetter. 1987. Treefalls revisited: gap dynamics in the southern Appalachians. *Ecology* 68(2): 417–424.

Schuler, T.M., and McClain, W.R. 2003. Fire history of a ridge and valley oak forest. USDA Forest Service Research Paper NE-724, Northeastern Research Station, Newtown Square, Pennsylvania, USA.

Seymour, R.S., and M.L. Hunter. 1999. Principles of ecological forestry. *In:* M.L. Hunter, ed. *Maintaining Biodiversity in Forest Ecosystems*. Cambridge University Press: Cambridge, United Kingdom. pp. 22–61.

Sheppard, D.E. 2001. *Native American Conquest: The Southeast*. The Native American Conquest Corp. http://floridahistory.com/southeastern-conquest-trails.pdf.

Shumway, D.L., M.D. Abrams, and C.M. Ruffner. 2001. A 400-year history of fire and oak recruitment in an old-growth forest in western Maryland, U.S.A. *Canadian Journal of Forest Research* 31: 1437–1443.

Silver, T. 1990. *A New Face on the Countryside: Indians, Colonists, and Slaves in South Atlantic Forests, 1500–1800*. Cambridge University Press: Cambridge, United Kingdom. 199 pp.

Speer, J.H. 2010. *Fundamentals of Tree-Ring Research*. University of Arizona Press: Tucson. 333 pp.

Stambaugh, M.C., R.P. Guyette, and C. Putnam. 2005. Fire in the pines: a 341-year fire and human history at Big Spring Pines Natural Area, Ozark National Scenic Riverways. *Park Science* 23(2): 43–47.

Stambaugh, M.C., R.P. Guyette, and J.M. Marschall. 2011. Longleaf pine (*Pinus palustris* Mill.) fire scars reveal new details of a frequent fire regime. *Journal of Vegetation Science* 22(6): 1094–1104.

Stoddard, H. 1931. The use and abuse of fire on southern quail preserves. *In:* H.L. Stoddard, Sr. (ed.), *The Bobwhite Quail: Its Habits, Preservation, and Increase*. Scribner: New York. 401–414.

Stokes, M.A., and T.L. Smiley. 1968. *An Introduction to Tree-Ring Dating*. The University of Chicago Press: Chicago. 73 pp.

Sutherland, E.K., H.D. Grissino-Mayer, C.A. Woodhouse, W.W. Covington, S. Horn, L. Huckaby, R. Kerr, J. Kush, M. Moore, and T. Plumb. 1995. Two centuries of fire in a southwestern Virginia *Pinus pungens* community. *In:* Proceedings of the IUFRO Conference Inventory and Management Techniques in the Context of Catastrophic Events: Altered States of the Forest, June 21–24, 1993. Penn State University, Office for Remote Sensing of Earth Resources. 14 pp.

Toole, E.R. 1961. Fire scar development. *Southern Lumberman* 203: 111–112.

Touchan, R., and T.W. Swetnam. 1995. Fire history in ponderosa pine and mixed-conifer forests of the Jemez Mountains, northern New Mexico. Final Report, USDA Forest Service and USDI National Park Service, Bandelier National Monument, Los Alamos, New Mexico. 87 pp.

Trani, M.K. 2002. Southern Forest Resource Assessment highlights: terrestrial ecosystems and wildlife conservation. *Journal of Forestry* 100(7): 35–40.

USDA Forest Service. 2001. U.S. Forest Facts and Historical Trends. FS-696. USDA Forest Service, Washington, D.C. 18 pp.

Van Lear, D.H., and T.A. Waldrop. 1989. History, uses, and effects of fire in the Appalachians. General Technical Report SE-54, USDA Forest Service Southeastern Forest Experiment Station, Asheville, North Carolina.

Vose, J.M., W.T. Swank, B.D. Clinton, J.D. Knoepp, and L.W. Swift. 1999. Using stand replacement fires to restore southern Appalachian pine-hardwood ecosystems: effects on mass, carbon, and nutrient pools. *Forest Ecology and Management* 114: 215–226.

Waldrop, T.A., and P.H. Brose. 1999. A comparison of fire intensity levels for stand replacement of Table Mountain pine (*Pinus pungens* Lamb.) with prescribed fire. *Forest Ecology and Management* 113: 115–156.

Waldrop, T.A., N.T. Welch, P.H. Brose, K. J. Elliott, H.H. Mohr, E.A. Gray, F.H. Tainter, and L.E. Ellis. 2000. Current research on restoring ridgetop pine communities with stand replacement fire. *In*: Proceedings: Workshop on Fire, People, and the Central Hardwoods Landscape. pp. 103–109.

Waldrop, T.A., P.H. Brose, N.T. Welch, H.H. Mohr, E.A. Gray, F.H. Tainter, and L.E. Ellis. 2003. Are crown fires necessary for Table Mountain pine? *In:* Fire Conference 2000: the First National Congress on Fire Ecology, Prevention, and Management. K.E.M. Galley, R.C. Klinger, and N.G. Sugibara, eds. Miscellaneous Publication No.13. USDA Forest Service, Tall Timbers Research Station. pp. 157–163.

Walters, R.S., and H.W. Yawney. 1990. *Acer rubrum* L. (red maple). *In*: Silvics of North America Vol. 2. Hardwoods. R.M. Burns and B.H. Honkala, comp. U.S. Department of Agriculture *Agricultural Handbook* 654. pp. 60-67.

Watt, A.S. 1947. Pattern and process in the plant community. *Journal of Ecology* 35: 1–22.

Welch, N.T., T.A. Waldrop, and E.R. Buckner. 2000. Response of southern Appalachian Table Mountain pine (*Pinus pungens*) and pitch pine (*P. rigida*) stands to prescribed burning. *Forest Ecology and Management* 136: 185–197.

White, P.B. 2010. Decadal-scale trends in forest succession and climatic sensitivity in a red spruce-fraser fir forest at Roan Mountain, Pisgah and Cherokee National Forests. Master's thesis, Appalachian State University, Boone, North Carolina.

Whittaker, R.H. 1956. Vegetation of the Great Smoky Mountains. *Ecological Monographs* 26: 1–80.

Williams, C.E. 1998. History and status of Table Mountain pine-pitch pine forests of the southern Appalachian Mountains (USA). *Natural Areas Journal* 18(1): 81–90.

Williams, C.E., and W.C. Johnson. 1992. Factors affecting recruitment of *Pinus pungens* in the southern Appalachian Mountains. *Canadian Journal of Forest Research* 22: 878–887.

Williams, G.W. 2002. Aboriginal use of fire: are there any "natural" communities? USDA Forest Service, Washington Office, Washington, D.C.

Williams, M. 1989. *Americans and their Forests: A Historical Geography*. Cambridge University Press: Cambridge, United Kingdom. 624 pp.

Yamaguchi, D.K. 1991. A simple method for cross-dating increment cores from living trees. *Canadian Journal of Forest Research* 21: 414–416.

Zhang, Y., H.S. He, and J. Yang. 2008. The wildland-urban interface dynamics in the southeastern U.S. from 1990 to 2000. *Landscape and Urban Planning* 85: 155–162.

Zobel, D.B. 1969. Factors affecting the distribution of *Pinus pungens*, an Appalachian endemic. *Ecological Monographs* 39(3): 303–333.

APPENDICES

APPENDIX 1

Bartram Trail Plot Data

Tree identification number, diameter at breast height (DBH), species code*, and pith date** of trees sampled at all 10 plots at the BTR site.
*Species abbreviations are as follows: ACRU, *Acer rubrum*; NYSA, *Nyssa sylvatica*; QUCO, *Quercus coccinea*; QURU, *Quercus rubra*; QUMO, *Quercus montana*; CACO, *Carya cordiformis*; LITU, *Liriodendron tulipifera*; PIST, *Pinus strobus*; PIRI, *Pinus rigida*; PIVI, *Pinus virginiana*; PIEC, *Pinus echinata*; ACSA, *Acer saccharinum*
**Pith dates from a few cores could not be determined due to missing pieces of the core or excessive rot.

Tree ID	DBH	Species	Pith Date
1P001	11	NYSA	1971
1P002	16.9	NYSA	1928
1P003	29.8	PIRI	1906
1P004	7.2	NYSA	1970
1P005	8.2	ACRU	1981
1P006	18.9	ACRU	1974
1P007	6.5	PIST	1982
1P008	7.3	NYSA	1978
1P009	39.6	NYSA	1920
1P010	39.7	QUCO	1917
1P011	16.5	NYSA	1937
2P001	10	NYSA	1961
2P002	23.4	QUMO	1944
2P003	21.2	QUMO	1932
2P004	6.9	CACO	1970
2P005	24.2	QUMO	1920
2P006	7.9	NYSA	1978
2P007	14.2	NYSA	1977
2P008	8.5	ACRU	1974
2P009	5.4	ACRU	1979
2P010	10.8	ACRU	1978
2P011	51.4	QUMO	1890
2P012	5.6	ACRU	1974
2P013	13.2	CACO	1932
2P014	7.5	NYSA	1988
3P001	32.6	PIVI	1926
3P002	14.1	ACRU	1970
3P003	14.2	ACRU	1967
3P004	23.3	NYSA	1922
3P005	8.5	ACRU	1966
3P006	10.3	ACRU	1969
3P007	15.6	ACRU	1952
3P008	7.7	NYSA	1947
3P009	6	NYSA	1966
3P010	19.5	PIVI	1943
3P011	28.2	PIVI	1944
3P012	9.2	ACRU	1970
4P001	11.9	NYSA	1984
4P002	9.1	NYSA	1934
4P003	16.1	ACRU	1940
4P004	7	ACRU	1949

4P005	10.5	CACO	1933
4P006	16.6	NYSA	1969
4P007	7.7	LITU	1980
4P008	18.2	NYSA	1966
4P009	23.4	NYSA	1948
4P010	32.9	QUCO	1880
4P011	25.7	NYSA	1936
4P012	8.7	CACO	1954
4P013	18.1	NYSA	1936
4P014	7.4	NYSA	1969
5P001	18.7	QUMO	1931
5P002	8.9	CACO	1960
5P003	6.8	PIST	1989
5P004	17.3	NYSA	1938
5P005	42.5	QUCO	1927
5P007	30.1	NYSA	1926
5P008	47	QUMO	1931
5P009	21.4	QUMO	1939
5P010	26.2	QUMO	1923
6P001	17.8	PIRI	1930
6P002	58.7	PIRI	1937
6P003	29.2	LITU	1977
6P004	14.2	LITU	1972
6P005	21.3	PIRI	1928
6P006	5.5	NYSA	1996
6P007	5.3	ACRU	1978
6P008	10.6	ACRU	1961
6P009	5.3	ACRU	1991
6P010	14.1	LITU	1969
6P011	11.3	LITU	1976
6P012	8.6	NYSA	1979
6P013	26	PIRI	1934
7P001	7.4	ACRU	1975
7P002	16.8	NYSA	1940
7P003	11.5	NYSA	1943
7P004	69.5	QURU	1886
7P005	6.1	ACRU	1961
7P006	18	NYSA	1945
7P007	37.3	ACRU	1935
7P008	8.7	CACO	1946
7P009	25.9	LITU	1979
7P010	9.9	NYSA	1972
7P011	9.5	ACRU	1976

7P012	18.2	LITU	1971
7P013	5.1	ACRU	1956
7P014	14.1	LITU	1954
8P001	37.1	PIRI	1940
8P002	42.2	PIRI	1933
8P003	8	ACRU	1970
8P004	5.8	NYSA	1959
8P005	23.5	QURU	1942
8P006	19.3	NYSA	1952
8P007	17.4	ACRU	1948
8P008	34.6	ACRU	1940
8P009	10.8	ACRU	1970
9P001	23.5	NYSA	1946
9P002	33.2	NYSA	1934
9P003	18.6	NYSA	1952
9P004	33.8	QURU	1941
9P005	12.5	NYSA	1951
9P006	17.6	NYSA	1947
9P007	6.5	HATE	1990
9P008	7.5	ACRU	1973
10P001	20.6	ACRU	1966
10P002	11.1	LITU	1972
10P004	8.6	NYSA	1984
10P005	18.9	NYSA	1939
10P006	10.8	NYSA	1962
10P007	13.6	CACO	1927
10P008	9.1	ACRU	1956
10P009	22.6	PIVI	1941
10P011	11.6	NYSA	1971
10P012	10.6	CACO	1936
10P013	17.8	ACRU	1959

APPENDIX 2

Rainy Mountain Ridge Plot Data

Tree identification number, diameter at breast height (DBH), species code*, and pith date** of trees sampled at all 8 plots at the RMR site.
*Species abbreviations are as follows: ACRU, *Acer rubrum*; NYSA, *Nyssa sylvatica*; QUCO, *Quercus coccinea*; QURU, *Quercus rubra*; QUMO, *Quercus montana*; CACO, *Carya cordiformis*; LITU, *Liriodendron tulipifera*; PIST, *Pinus strobus*; PIRI, *Pinus rigida*; PIVI, *Pinus virginiana*; PIEC, *Pinus echinata*; ACSA, *Acer saccharinum*
**Pith dates from a few cores could not be determined due to missing pieces of the core or excessive rot.

Tree ID	DBH	Species	Pith Date
11P001	39.1	QURU	1940
11P002	9.8	LITU	1959
11P003	14.6	CACO	1933
11P004	22.7	NYSA	1935
11P005	28	PIRI	1938
11P006	39.7	NYSA	1945
11P007	9.2	CACO	1959
11P008	21.8	QURU	1922
11P009	61.9	PIRI	1880
12P001	14.7	NYSA	1956
12P002	13	CACO	1933
12P003	18.4	ACRU	1968
12P004	6.7	NYSA	1960
12P005	9.2	NYSA	1967
12P006	28.2	ACRU	1936
12P007	5.3	CACO	1956
12P008	23.7	ACSA	1964
12P009	27	NYSA	1968
12P010	18.7	ACRU	1952
12P011	48.1	PIRI	1931
12P012	5.9	QURU	1982
13P001	7.1	ACRU	1990
13P002	21.4	ACRU	1973
13P003	9.2	ACRU	1981
13P004	7.2	ACRU	1983
13P005	24.8	NYSA	1915
13P006	44.6	QUCO	1915
13P007	5.1	NYSA	1990
14P001	31	PIRI	1939
14P002	14.1	QUMO	1977
14P003	19	PIRI	1942
14P004	24.4	PIRI	1951
14P005	39.4	PIRI	1931
14P006	15.3	QUMO	1982
14P007	29.3	PIRI	1964
14P008	22.6	PIRI	1947
14P009	35.5	PIRI	1937
14P010	11.1	NYSA	1980
15P001	39.4	PIRI	1897
15P002	48.3	PIRI	1927
15P003	15.5	NYSA	1954

15P004	10.9	PIRI	1943
15P005	10	LITU	1982
15P006	32.3	PIRI	1907
15P007	6	QURU	1935
15P008	41.1	PIRI	1931
16P001	13.5	NYSA	1975
16P002	13.5	NYSA	1964
16P003	8.6	NYSA	1973
16P004	6.4	PIST	1983
16P005	6.3	PIST	1993
16P006	18.9	ACRU	1934
16P007	5.7	QURU	1970
16P008	7	PIST	1985
17P001	37.9	PIRI	1936
17P002	10.5	NYSA	1974
17P003	47.9	PIRI	1935
17P004	14	NYSA	1962
17P005	12	ACRU	1965
17P006	5.7	NYSA	1975
17P007	6.4	ACRU	1968
17P008	29.1	PIRI	1964
17P009	7	NYSA	1960
17P010	5.1	NYSA	1976
17P011	14.5	PIRI	1972
17P012	16.6	PIRI	1966
17P013	5.4	NYSA	1976
17P014	8.9	NYSA	1977
17P015	12.5	LITU	1980
18P001	9.1	ACRU	1959
18P002	31.6	PIRI	1907
18P003	14.1	QURU	1930
18P004	37.5	QURU	1933
18P005	5.9	CACO	1990
18P006	30.2	PIVI	1948
18P007	28.7	NYSA	1926
18P008	28.6	PIVI	1940
18P010	9.3	ACRU	1960
18P011	51	PIRI	1930

APPENDIX 3

Rainy Mountain West Plot Data

Tree identification number, diameter at breast height (DBH), species code*, and pith date** of trees sampled at all 12 plots at the RMW site.
*Species abbreviations are as follows: ACRU, *Acer rubrum*; NYSA, *Nyssa sylvatica*; QUCO, *Quercus coccinea*; QURU, *Quercus rubra*; QUMO, *Quercus montana*; CACO, *Carya cordiformis*; LITU, *Liriodendron tulipifera*; PIST, *Pinus strobus*; PIRI, *Pinus rigida*; PIVI, *Pinus virginiana*; PIEC, *Pinus echinata*; ACSA, *Acer saccharinum*
**Pith dates from a few cores could not be determined due to missing pieces of the core or excessive rot.

Tree ID	DBH(cm)	Species	Pith Date
19P001	6.8	NYSA	1963
19P002	19.5	ACRU	1949
19P003	16.6	ACRU	1960
19P004	23.1	QUMO	1968
19P005	25.5	PIRI	1942
19P006	11.5	QUMO	1951
19P007	17.3	QUMO	1961
19P008	39.4	ACRU	1966
20P001	32.7	ACSA	x
20P002	29.1	PIEC	1939
20P003	25.8	PIEC	1946
20P004	17.1	QUMO	1931
20P005	15.9	NYSA	1959
20P006	27.9	NYSA	1973
21P001	21.4	NYSA	1952
21P002	24.2	PIRI	1938
21P003	18.3	NYSA	1960
21P004	44	PIRI	1935
21P005	17.5	NYSA	1967
21P006	26	PIRI	1939
21P007	27.3	PIRI	1947
21P008	27.1	QUMO	1933
21P009	5.1	ACRU	1978
21P010	28.9	NYSA	1963
21P011	42.9	PIRI	1932
22P001	32.4	QUCO	1947
22P002	36.2	PIRI	1936
22P003	20.3	QURU	1927
22P004	20.1	ACRU	1965
22P005	13	ACRU	1977
22P006	7.2	ACRU	1976
23P001	12.3	ACRU	1982
23P002	43	PIEC	1936
23P003	5.7	CACO	1983
23P004	8.5	QUMO	1979
23P005	31.9	PIST	1978
23P006	12.1	PIEC	1981
23P007	53.9	PIEC	1928
23P008	5.1	ACRU	1970
23P009	11.3	ACRU	1974
24P001	17.8	CACO	1926

24P002	31.6	PIVI	1951
24P003	13.6	CACO	1960
24P004	38.1	PIVI	1946
24P005	8.3	ACRU	1947
24P006	37.4	PIVI	1925
24P007	11.1	NYSA	1976
24P008	10.5	NYSA	1975
24P009	48.5	PIVI	1921
24P010	5.5	CACO	1956
24P011	10	QUMO	1953
25P001	14	NYSA	1930
25P002	21.9	QURU	1969
25P003	30.2	NYSA	1905
25P004	13.7	NYSA	1930
25P005	16.9	NYSA	1962
25P006	10.2	PIRI	1965
25P007	10.8	PIRI	1969
25P008	19.1	PIRI	1956
25P009	19.5	NYSA	1924
25P010	22.7	NYSA	1970
25P011	10.4	PIRI	1990
26P001	13.9	QUMO	1933
26P002	19.1	PIEC	1946
26P003	9.8	NYSA	1970
26P004	15.2	PIRI	1948
26P005	15.3	NYSA	1956
26P006	22.9	QUCO	1930
26P007	13.5	NYSA	1979
26P008	9.3	NYSA	1954
26P009	9.2	NYSA	1974
26P010	17.5	NYSA	1948
26P011	15.1	PIEC	1941
27P001	14.1	NYSA	1965
27P002	8.8	ACRU	1967
27P003	26.8	PIRI	1939
27P004	41.1	PIRI	x
27P006	17	PIRI	1940
27P007	12.2	PIVI	1955
27P008	12.3	PIVI	1945
27P009	33	PIVI	1938
27P010	13.3	NYSA	1962
27P011	10.1	NYSA	1994
27P012	35.3	QUCO	1933

27P013	17.5	NYSA	1961
28P001	8.3	NYSA	1972
28P002	17.2	QURU	1946
28P003	29.4	PIRI	1947
28P004	27.1	PIRI	1954
28P005	11.8	ACRU	1968
28P006	22	QUCO	1934
28P007	37.2	PIRI	1941
28P008	25.8	QUCO	1933
28P009	26.5	QUCO	1927
29P001	10.7	NYSA	1959
29P002	27.2	PIRI	1949
29P003	45	PIRI	1930
29P004	11.7	ACRU	1983
29P005	10.4	ACRU	1935
29P006	16.2	NYSA	1985
29P007	6.4	NYSA	1972
29P008	32.6	PIRI	1921
29P009	10.6	NYSA	1986
30P001	22.3	NYSA	1974
30P002	18.2	NYSA	1948
30P003	7.8	PIVI	1998
30P004	10.5	NYSA	1975
30P005	12.2	NYSA	1985
30P006	23.4	QUMO	1916
30P007	21.6	ACRU	1973
30P008	13.2	ACRU	1958
30P009	12.7	ACRU	1944

APPENDIX 4

Fire history data for Bartram Trail

Summary statistics from FHX2 from each fire scarred sample. Includes series identification, innermost ring date, outermost ring date, number of rings in sample, year of fire scar, season of fire scar*, total number of fire scars, sample mean fire interval, and average number of years per fire for each individual sample and summary statistics for the site as a whole.
*Season in which the fire scar occurred is denoted as: E, early portion of the earlywood; M, middle portion of the earlywood; L, late portion of the earlywood; A, latewood; U, unclear

Series 1 : BTR006
Inner Ring : 1934
Bark Date : 2012
Length of sample : 79
Number in final analysis : 29
Information on fire history :
1984 D fire scar
Total number of fire scars : 1
Average number years per fire : 29.0

Series 2 : BTR007
Pith Date : 1920
Outer Ring : 1992
Length of sample : 73
Number in final analysis : 19
Information on fire history :
1974 D fire scar
1991 E fire scar FI = 17
Total number of fire scars : 2
Average number years per fire : 9.5
Sample mean fire interval: 17.0

Series 3 : BTR010
Inner Ring : 1924
Bark Date : 2012
Length of sample : 89
Number in final analysis : 45
Information on fire history :
1968 D fire scar
Total number of fire scars : 1
Average number years per fire : 45.0

Series 4 : BTR017
Pith Date : 1926
Outer Ring : 1993
Length of sample : 68
Number in final analysis : 22
Information on fire history :
1972 E fire scar
Total number of fire scars : 1
Average number years per fire : 22.

Series 5 : BTR018
Pith Date : 1929
Bark Date : 2012
Length of sample : 84
Number in final analysis : 45
Information on fire history :
1968 E fire scar
Total number of fire scars : 1
Average number years per fire : 45.0

Series 6 : BTR019
Pith Date : 1915
Bark Date : 2012
Length of sample : 98
Number in final analysis : 45
Information on fire history :
1968 U fire scar
Total number of fire scars : 1
Average number years per fire : 45.0

Series 7 : BTR021
Inner Ring : 1951
Bark Date : 2012
Length of sample : 62
Number in final analysis : 37
Information on fire history :
1976 D fire scar
Total number of fire scars : 1
Average number years per fire : 37.0

Final Summary Information for Entire Site

Beginning year : 1900
Last year: 2012
Length of fire chronology : 113
Total number of samples : 7
Total number of recorder years: 242
Total number of fire scars: 8
Total number of all indicators: 8
Avg number of years per fire: 30.3
Avg number of years per all injuries: 30.3
Avg all sample mean fire intervals: 2.4
Total number of years with fire:6
Percentage of years with fire:5.3
Percentage of years without fire: 94.7
Percentage of years MFI:18.8

APPENDIX 5

Fire history data for Rainy Mountain Ridge

Summary statistics from FHX2 from each fire scarred sample. Includes series identification, innermost ring date, outermost ring date, number of rings in sample, year of fire scar, season of fire scar*, total number of fire scars, and average number of years per fire.
*Season in which the fire scar occurred is denoted as: E, early portion of the earlywood; M, middle portion of the earlywood; L, late portion of the earlywood; A, latewood; U, unclear

Series 1 : RMR001
Pith Date : 1933
Bark Date : 2012
Length of sample : 80
Number in final analysis : 69
Information on fire history :
1944 U fire scar
1983 E fire scar FI = 39
Total number of fire scars : 2
Total number all indicators : 2
Average number years per fire : 34.5
Sample mean fire interval : 39.0

Series 2 : RMR002
Pith Date : 1920
Bark Date : 2012
Length of sample : 93
Number in final analysis : 41
Information on fire history :
1972 D fire scar
1980 D fire scar FI = 8
2010 E fire scar FI = 30
Total number of fire scars : 3
Total number all indicators : 3
Average number years per fire : 13.7
Sample mean fire interval : 19.0

Series 3 : RMR003
Inner Ring : 1948
Bark Date : 2012
Length of sample : 65
Number in final analysis : 49
Information on fire history :
1964 M fire scar
1972 M fire scar FI = 8
1983 D fire scar FI = 11
Total number of fire scars : 3
Total number all indicators : 3
Average number years per fire : 16.3
Sample mean fire interval : 9.5

Series 4 : RMR004
Pith Date : 1936
Bark Date : 2012
Length of sample : 77
Number in final analysis : 52
Information on fire history :
1961 D fire scar
1967 D fire scar FI = 6
1977 D fire scar FI = 10
1985 D fire scar FI = 8
Total number of fire scars : 4
Total number all indicators : 4
Average number years per fire : 13.0
Sample mean fire interval : 8.0

Series 5 : RMR005
Pith Date : 1927
Bark Date : 2012
Length of sample : 86
Number in final analysis : 51
Information on fire history :
1962 D fire scar
1983 U fire scar FI = 21
1989 U fire scar FI = 6
1993 M fire scar FI = 4
Total number of fire scars : 4
Total number all indicators : 4
Average number years per fire : 12.7
Sample mean fire interval : 10.3

Series 6 : RMR006
Inner Ring : 1945
Bark Date : 2012
Length of sample : 68
Number in final analysis : 33
Information on fire history :
1980 U fire scar
Total number of fire scars : 1
Total number all indicators : 1
Average number years per fire : 33.0

Series 7 : RMR007
Inner Ring : 1924
Bark Date : 2012
Length of sample : 89
Number in final analysis : 39
Information on fire history :
1974 D fire scar
1993 U fire scar FI = 19
Total number of fire scars : 2
Total number all indicators : 2
Average number years per fire : 19.5
Sample mean fire interval : 19.0

Series 8 : RMR008
Inner Ring : 1947
Bark Date : 2012
Length of sample : 66
Number in final analysis : 24
Information on fire history :
1989 D fire scar
Total number of fire scars : 1
Total number all indicators : 1
Average number years per fire : 24.0

Series 9 : RMR009
Inner Ring : 1921
Bark Date : 2012
Length of sample : 92
Number in final analysis : 41
Information on fire history :
1972 D fire scar
Total number of fire scars : 1
Total number all indicators : 1
Average number years per fire : 41.0

Series 10 : RMR010
Pith Date : 1971
Bark Date : 2012
Length of sample : 42
Number in final analysis : 12
Information on fire history :
2001 D fire scar
Total number of fire scars : 1
Total number all indicators : 1
Average number years per fire : 12.0

Series 11 : RMR011
Inner Ring : 1914
Outer Ring : 1952
Length of sample : 39
Number in final analysis : 29
Information on fire history :
1924 E fire scar
Total number of fire scars : 1
Total number all indicators : 1
Average number years per fire : 29.0

Series 12 : RMR016
Inner Ring : 1905
Bark Date : 2012
Length of sample : 108
Number in final analysis : 20
Information on fire history :
1993 M fire scar
2001 D fire scar FI = 8
2007 D fire scar FI = 6
Total number of fire scars : 3
Total number all indicators : 3
Average number years per fire : 6.7
Sample mean fire interval : 7.0

Series 13 : RMR018
Pith Date : 1959
Bark Date : 2012
Length of sample : 54
Number in final analysis : 18
Information on fire history :
1995 E fire scar
2002 D fire scar FI = 7
Total number of fire scars : 2
Total number all indicators : 2
Average number years per fire : 9.0
Sample mean fire interval : 7.0

Final Summary Information for Entire Site

Beginning year: 1900
Last year: 2012
Length of fire chronology:113
Total number of samples:13
Total number of recorder years:478
Total number of fire scars:28
Total number of all indicators:28
Avg number of years per fire:17.1
Avg number of years per all injuries : 17.1
Avg all sample mean fire intervals:9.1
Total number of years with fire:19
Percentage of years with fire:16.8
Percentage of years without fire:83.2
Percentage of years MFI:5.9

APPENDIX 6

Tree-ring measurements for Rainy Mountain yellow pines

Measurements are shown without decimal points in the format recommended by the International Tree-Ring Data Bank, World Data Center for Paleoclimatology, but actual values can be found by dividing by 1000. Each row represents a decade, with a ring width measurement listed for each year.

3P011	31944	3216	3101	3743	2420	2254	3398				
3P011	31950	3344	2802	1774	2248	1646	1624	2346	1423	1821	1691
3P011	31960	1831	1733	1449	1344	1156	993	1029	1192	859	838
3P011	31970	809	893	860	701	700	1652	1258	1549	1096	579
3P011	31980	485	769	804	591	490	730	497	615	612	914
3P011	31990	1587	1721	1530	1222	758	997	1118	1134	1224	1383
3P011	32000	1344	657	494	526	1091	1089	985	615	835	1296
3P011	32010	975	1340	1560	-9999						
6P002B	a1937	193	8723	5659							
6P002B	a1940	5707	4014	4857	4409	4383	2756	3436	2830	3055	2758
6P002B	a1950	1523	2048	2448	1856	2076	2375	4370	3508	3622	2976
6P002B	a1960	1816	2053	3929	2619	2046	2254	2093	2764	3536	3135
6P002B	a1970	1900	2379	2135	2306	3002	2738	2434	2846	2782	1624
6P002B	a1980	1125	1693	2248	2646	2814	4776	2833	1313	1733	2633
6P002B	a1990	3773	2832	2245	3858	4293	4983	2987	2571	2011	1658
6P002B	a2000	3084	3360	2645	2013	2000	885	623	310	552	1101
6P002B	a2010	1499	1666	1781	-9999						
6P005	61933	1112	1115	792	2380	2619	3731	2586			
6P005	61940	2501	2745	2893	2764	2425	2216	2914	2723	1886	1950
6P005	61950	2323	2508	1189	1552	1759	1462	1872	1049	1849	1460
6P005	61960	1348	971	1303	950	1000	850	717	1007	1160	925
6P005	61970	1134	1054	456	529	814	1064	1125	1083	675	494
6P005	61980	658	879	827	933	890	908	430	508	942	1237
6P005	61990	1352	963	1015	793	667	869	668	816	392	869
6P005	62000	646	594	668	795	995	625	1293	805	611	605
6P005	62010	1417	1653	1329	-9999						
6P013	61934	929	2094	3323	4009	3248	2817				
6P013	61940	3612	3306	2905	2417	1863	2180	2581	2563	2135	2798
6P013	61950	3647	2933	1497	1835	2183	2595	2637	2820	2655	1993
6P013	61960	2107	1164	1938	1912	1030	1269	1366	1044	1015	1639
6P013	61970	1045	1560	1049	713	1399	1245	907	991	1123	991
6P013	61980	916	1006	1181	1184	1383	1420	307	517	629	801
6P013	61990	1366	1493	1415	1133	1257	739	686	538	370	690
6P013	62000	423	382	508	868	1069	584	698	891	721	1025
6P013	62010	1175	1311	1711	-9999						
8P001	81944	3461	1962	2740	2199	3056	2905				
8P001	81950	1506	1906	1030	1528	2150	2007	2835	2951	3007	3071
8P001	81960	2296	1539	1798	1267	1202	1016	839	1122	1862	1359
8P001	81970	815	902	1288	2389	1901	1981	1594	1216	1446	1639
8P001	81980	1519	1395	1594	1490	2036	1344	508	467	586	1426
8P001	81990	3299	2993	2528	1891	1562	907	1301	2275	1133	1393
8P001	82000	2528	2147	1602	1841	3216	2147	870	405	475	997
8P001	82010	3039	3074	2990	-9999						
8P002	81933	931	1354	1650	2475	2446	3331	3045			
8P002	81940	3767	4591	5253	3746	3598	3513	5927	3262	3894	4783
8P002	81950	3809	3429	3936	3302	3979	3621	5010	3424	3589	3171
8P002	81960	1977	2550	2385	2073	3316	2927	2357	2437	2434	2497
8P002	81970	1890	2195	1703	2094	2040	3065	2376	1795	1681	2104
8P002	81980	1630	1909	1684	1217	801	914	493	543	713	1189
8P002	81990	2296	2437	1098	1341	1558	1287	1714	1612	1706	2110
8P002	82000	1938	1797	1358	1504	2050	1114	1031	1049	810	1534
8P002	82010	2838	3130	3117	-9999						
12P011	11935	2822	2534	2264	2044	1999					
12P011	11940	2405	3112	3555	3334	3555	2304	2895	2552	3050	3608
12P011	11950	3796	3213	2734	3580	3691	2522	2905	2876	4172	3848
12P011	11960	2908	3028	2351	2453	3393	3540	3451	3699	4407	4176
12P011	11970	3911	2965	2531	2310	2383	2470	1866	2078	1886	2224

12P011	11980	1778	1886	1777	1545	1856	2891	1804	1544	1649	1777
12P011	11990	2668	3592	3040	2768	2810	3329	2884	3472	2794	2180
12P011	12000	2859	1865	1801	1834	2782	2102	2106	992	1607	2031
12P011	12010	2386	2933	2990	-9999						
17P003	11940	1847	1148	1449	1202	1107	519	726	974	1209	1073
17P003	11950	920	1105	1074	994	1077	444	2006	2261	3191	2890
17P003	11960	1989	2997	4458	3186	2830	4038	3667	5397	4465	3688
17P003	11970	3114	3550	2496	2207	2809	4150	2305	3469	3596	3290
17P003	11980	2976	3827	3861	3254	3257	3912	1733	1634	1661	2460
17P003	11990	2729	3305	1909	2332	2253	1353	1631	2768	1733	2658
17P003	12000	2853	1606	1816	1401	1612	1928	1715	1334	1400	2015
17P003	12010	3713	5314	3247	-9999						
17P008	a1966	25	5451	4744	3363						
17P008	a1970	2642	1876	1086	1611	1694	1900	1426	2280	1263	1153
17P008	a1980	1528	2189	1735	1685	2587	2290	2006	2561	1588	3605
17P008	a1990	5460	3831	2484	2779	2338	1609	2640	2219	1347	1866
17P008	a2000	2159	1962	2768	2841	3514	3096	2794	1566	2036	5343
17P008	a2010	7156	3302	4404	-9999						
19P005	11946	563	539	529	487						
19P005	11950	410	275	571	275	338	402	508	732	1227	995
19P005	11960	1047	1267	785	577	898	469	969	1876	2564	1596
19P005	11970	1393	683	643	660	971	2644	2012	2096	2030	1229
19P005	11980	715	1963	2721	2981	2608	3764	2363	1768	1812	1853
19P005	11990	1600	3954	2423	2269	2593	2231	1958	2805	1553	2323
19P005	12000	2351	1977	1958	2338	3679	2685	1841	1280	2117	2414
19P005	12010	3207	3154	3026	-9999						
23P007	21933	4554	4614	3787	3746	2018	2550	2647			
23P007	21940	3109	3379	2811	3269	4047	3164	3731	3998	3450	3344
23P007	21950	2665	2454	1883	2338	3196	2226	2792	3464	3732	3061
23P007	21960	1957	2493	2898	1853	1882	2129	1565	2455	3648	2208
23P007	21970	1595	1643	1213	944	1484	1366	905	2827	3478	2585
23P007	21980	1594	1802	2341	3032	1546	3557	2245	1419	2500	2392
23P007	21990	5954	4159	1250	1818	1646	1100	1166	2032	1562	1562
23P007	22000	2678	2168	2164	1626	2520	1648	1484	953	1331	1558
23P007	22010	3698	2941	2478	-9999						
24P004	1950	1655	1648	1007	1766	2770	3654	2987	2816	4143	4274
24P004	1960	3242	3955	4035	2711	2672	2496	2573	3930	4069	5067
24P004	1970	3179	3944	3007	2634	4446	5971	3166	3787	3575	2240
24P004	1980	2528	3367	3265	3808	3198	4093	2915	1709	1250	2452
24P004	1990	3590	4301	2204	2145	1310	1838	1755	2455	3192	2242
24P004	2000	1694	2370	1576	1278	2177	2037	2298	1929	1901	1685
24P004	2010	1339	1318	1270	-9999						
24P009	21924	2559	1449	363	841	2310	1819				
24P009	21930	1039	1072	345	2086	1734	2374	2350	1830	1768	2208
24P009	21940	3122	3903	2943	3308	2471	2615	3592	3462	3050	3978
24P009	21950	3371	3361	2848	3440	1918	2036	4673	3233	3763	4515
24P009	21960	2678	2567	4396	4426	3728	3171	2762	5660	5373	5663
24P009	21970	5609	4482	2353	1312	2527	3190	2639	3884	4105	2548
24P009	21980	1742	2682	2650	2306	1291	1857	1143	1121	707	986
24P009	21990	2017	3696	1946	1821	1067	1528	970	1380	1624	1014
24P009	22000	1356	933	1123	1123	1484	1221	1173	890	778	855
24P009	22010	1050	1192	868	-9999						
BTR006	B1936	2720	3087	3232	3509						
BTR006	B1940	3210	2637	2484	2739	2874	2086	3059	3066	2417	3324
BTR006	B1950	3016	2837	1929	1846	1670	1648	2368	1755	2538	2325
BTR006	B1960	1611	1286	1817	1702	2210	2018	1761	2305	2727	1861
BTR006	B1970	1818	1987	1860	2135	3314	3511	2647	2852	2852	2429

BTR006	B1980	1668	1754	1901	3234	1975	2274	1666	1458	1521	3655
BTR006	B1990	5856	5621	3824	3675	4020	2253	1751	1637	1067	1522
BTR006	B2000	2453	1247	1839	2389	2816	2273	1184	1027	685	1680
BTR006	B2010	1787	2368	2767	-9999						
BTR007	B1920	1227	1782	1798	1294	2193	1852	1800	2104	2472	2255
BTR007	B1930	1985	1513	1166	909	898	1180	1585	803	1267	1246
BTR007	B1940	1609	1977	1914	2222	2083	1773	2388	2071	1647	2665
BTR007	B1950	2275	2031	941	1122	718	1038	1567	1314	1333	932
BTR007	B1960	975	400	635	360	254	202	323	245	700	885
BTR007	B1970	512	853	883	318	864	847	1731	2207	2252	1794
BTR007	B1980	1283	1904	2212	2878	3078	2729	1055	1944	4020	7498
BTR007	B1990	3967	1357	-9999							
BTR010	B1924	1068	912	754	640	1034	1240				
BTR010	B1930	897	941	1070	1029	963	1299	1413	841	1627	1398
BTR010	B1940	1932	2871	2669	2833	3009	2818	4286	3618	3313	4718
BTR010	B1950	4166	3315	1658	2358	3224	2830	3464	2895	3530	2558
BTR010	B1960	2208	1584	2303	1150	793	895	947	1744	2015	2567
BTR010	B1970	2049	1764	933	1717	3012	2828	1762	1359	1161	1243
BTR010	B1980	1585	1999	1798	1724	1866	2268	857	410	881	1470
BTR010	B1990	1516	1188	998	1116	809	658	687	510	592	761
BTR010	B2000	592	802	1153	938	864	576	581	602	339	311
BTR010	B2010	955	1692	1698	-9999						
BTR015A	1889	4762									
BTR015A	1890	4046	3810	2774	2272	2235	964	735	1501	1132	4685
BTR015A	1900	283	1255	3948	1642	1600	2397	3394	3568	3114	4055
BTR015A	1910	3719	3042	2659	2109	2452	4352	2325	2536	2235	1858
BTR015A	1920	1776	2281	2534	1818	1860	1479	1901	2282	3000	3658
BTR015A	1930	5340	2397	1473	1053	1644	1564	2833	3235	3315	3728
BTR015A	1940	3381	4216	2713	1723	1257	2321	3038	3671	2912	2826
BTR015A	1950	2269	2521	1649	2030	1987	1606	1606	1521	1605	2364
BTR015A	1960	1604	762	1050	718	465	422	592	716	754	1455
BTR015A	1970	877	1471	1345	1294	1047	1259	1177	1387	880	545
BTR015A	1980	420	677	803	550	761	468	293	379	463	463
BTR015A	1990	1177	1382	1382	1257	971	802	885	885	1181	1477
BTR015A	2000	1092	966	1308	764	1310	803	1269	1099	1015	1057
BTR015A	2010	1015	1225	1858	-9999						
BTR015B	B1892	1498	2925	2401	1852	735	986	2344	4733		
BTR015B	B1900	126	1507	4288	1538	1874	3120	4760	3827	3273	3759
BTR015B	B1910	3519	2485	3089	1741	1350	3729	3415	3146	2884	2438
BTR015B	B1920	1801	1853	2629	2407	2773	1989	1716	1789	2439	4045
BTR015B	B1930	7368	5626	2702	1853	2674	3369	3325	2919	3081	2644
BTR015B	B1940	3247	3814	3074	2714	1674	2113	2465	1387	1493	1666
BTR015B	B1950	1528	1586	1057	1372	1456	1399	1704	2017	1764	1864
BTR015B	B1960	1434	937	1217	921	882	490	644	1186	1187	1631
BTR015B	B1970	1187	1164	1311	1169	1779	2053	1566	1909	1369	983
BTR015B	B1980	933	891	1547	1845	1802	1907	997	827	763	760
BTR015B	B1990	1032	1727	1270	1182	1608	1271	1360	1350	1382	1311
BTR015B	B2000	1166	789	949	733	1421	750	1165	952	695	905
BTR015B	B2010	1052	1618	2137	-9999						
BTR016A	B1899	2725									
BTR016A	B1900	382	1589	2308	879	2317	2281	2468	2600	2547	1675
BTR016A	B1910	2544	2113	2796	2446	1801	1817	2212	2558	2029	2097
BTR016A	B1920	1621	1221	1287	1457	1988	1877	2032	2021	1562	2024
BTR016A	B1930	2721	2252	1855	1780	1583	1603	1724	2134	1865	1838
BTR016A	B1940	2039	2266	2535	2317	1692	1333	2480	1590	1103	2396
BTR016A	B1950	1951	1759	1123	1545	1977	1835	2077	2077	1971	1842
BTR016A	B1960	1900	1277	1483	1611	1372	760	1038	1060	1060	1527

BTR016A	B1970	1187	1230	997	932	912	1461	752	852	640	338
BTR016A	B1980	274	382	402	402	529	446	322	258	500	590
BTR016A	B1990	1105	1334	636	1012	915	909	1196	1930	1214	1036
BTR016A	B2000	821	835	1119	836	1070	600	863	1077	873	902
BTR016A	B2010	779	841	1864	-9999						
BTR016B	B1890	1302	3193	3688	4047	3429	3742	3517	3708	2938	3396
BTR016B	B1900	647	2289	2865	1462	2523	2297	3157	3226	3668	2502
BTR016B	B1910	2653	3211	3593	2447	2017	2781	2491	2576	2253	2160
BTR016B	B1920	2270	1934	1234	1883	1960	1674	1816	1815	1673	2022
BTR016B	B1930	2904	2293	1951	1870	1555	1808	1412	1766	1904	1715
BTR016B	B1940	1744	2898	2973	2649	1913	2142	2541	1957	1481	2311
BTR016B	B1950	2491	2269	1388	1973	1922	1982	2068	1984	2234	1877
BTR016B	B1960	1579	832	1221	1219	1054	929	1116	1059	1366	1735
BTR016B	B1970	1412	2007	1489	984	1242	989	1189	1393	1007	532
BTR016B	B1980	389	500	602	536	482	744	319	184	339	620
BTR016B	B1990	1147	915	649	678	920	831	849	1382	1094	1068
BTR016B	B2000	1009	793	829	742	965	668	1060	1152	977	1106
BTR016B	B2010	833	859	1672	-9999						
BTR019	1916	1252	1057	918	1117						
BTR019	1920	495	560	1120	868	1028	1051	693	874	1444	1904
BTR019	1930	1484	1179	821	576	949	929	1464	1354	1224	1069
BTR019	1940	795	1219	970	968	1010	1094	1012	1180	1049	875
BTR019	1950	1201	1141	921	897	845	803	1098	1004	1243	1003
BTR019	1960	1099	664	880	713	673	589	509	465	635	843
BTR019	1970	635	971	972	888	973	1549	655	544	422	380
BTR019	1980	386	501	930	1139	886	1055	538	519	846	803
BTR019	1990	888	1141	888	761	846	718	540	529	631	690
BTR019	2000	731	674	590	577	688	590	506	507	591	549
BTR019	2010	676	591	792	-9999						
RMR005	R1928	1366	1436								
RMR005	R1930	1903	1130	762	1310	1123	886	719	537	1640	1263
RMR005	R1940	1550	1435	1051	1149	1264	1001	1256	1152	1332	1288
RMR005	R1950	1228	991	274	527	1117	802	652	1038	923	846
RMR005	R1960	614	173	292	360	296	254	466	1324	1405	1625
RMR005	R1970	781	1254	853	291	652	789	592	778	825	633
RMR005	R1980	720	846	736	781	719	494	527	754	867	992
RMR005	R1990	1303	1327	969	1585	741	508	529	635	868	1080
RMR005	R2000	781	934	508	1058	861	705	783	762	974	847
RMR005	R2010	1079	1183	1232	-9999						
RMR007	R1925	1802	1896	2498	2343	2757					
RMR007	R1930	3712	3131	2598	2755	3005	3322	2906	2837	2455	2111
RMR007	R1940	2072	3488	2060	1820	1644	895	903	1169	1395	1522
RMR007	R1950	1659	1229	508	812	1258	1543	1269	1047	1442	1287
RMR007	R1960	1136	1322	1531	1403	1026	1368	1458	2359	2376	2389
RMR007	R1970	1416	1390	1938	1465	3470	2961	1142	882	1003	721
RMR007	R1980	571	818	761	1226	1417	1038	822	847	1374	1056
RMR007	R1990	2193	1807	1260	1287	778	464	358	403	447	687
RMR007	R2000	817	532	341	425	460	846	896	593	424	730
RMR007	R2010	770	1176	1227	-9999						
BTR017	B1926	1671	1909	1056	4257						
BTR017	B1930	3378	2662	834	2241	973	1648	178	1029	3515	4057
BTR017	B1940	4821	4285	3554	3700	3749	2519	3446	3899	4089	4034
BTR017	B1950	3359	2058	1205	1544	2202	2239	3535	3177	3122	2650
BTR017	B1960	3668	2401	2694	1738	1906	1972	1694	1802	1187	1988
BTR017	B1970	2332	3005	1350	1251	1435	950	4368	6307	4823	2873
BTR017	B1980	3508	3713	3420	3377	3458	1657	2122	1806	1624	1231
BTR017	B1990	1623	1417	927	628	-9999					

11P009B	11892	2257	1623	1932	1451	2981	2338	2689	2736		
11P009B	11900	1050	4211	2248	1963	3776	4664	5894	4167	4570	4071
11P009B	11910	3802	3775	3938	3002	2968	5878	4114	3241	2120	3519
11P009B	11920	2663	1723	1933	2348	2268	2700	3171	2455	2725	3910
11P009B	11930	2716	2681	1459	1293	4314	4330	2745	3302	2303	1501
11P009B	11940	1587	1839	2178	1940	1463	1925	3016	1752	2059	1975
11P009B	11950	2227	2599	3248	2642	2555	1791	1947	1224	2637	2576
11P009B	11960	2027	1521	1598	1253	1536	1601	1819	1393	1465	1910
11P009B	11970	2234	1853	1350	1180	1138	1436	1253	1707	1193	1073
11P009B	11980	675	914	1087	857	672	945	710	959	813	729
11P009B	11990	711	1269	759	1009	1314	834	998	1009	709	817
11P009B	12000	948	814	843	863	899	784	730	590	551	641
11P009B	12010	570	592	775	-9999						
RMR005	R1928	1366	1436								
RMR005	R1930	1903	1130	762	1310	1123	886	719	537	1640	1263
RMR005	R1940	1550	1435	1051	1149	1264	1001	1256	1152	1332	1288
RMR005	R1950	1228	991	274	527	1117	802	652	1038	923	846
RMR005	R1960	614	173	292	360	296	254	466	1324	1405	1625
RMR005	R1970	781	1254	853	291	652	789	592	778	825	633
RMR005	R1980	720	846	736	781	719	494	527	754	867	992
RMR005	R1990	1303	1327	969	1585	741	508	529	635	868	1080
RMR005	R2000	781	934	508	1058	861	705	783	762	974	847
RMR005	R2010	1079	1183	1232	-9999						
RMR011	R1914	1101	2400	1614	1940	1122	1441				
RMR011	R1920	887	2606	1653	474	643	5722	4225	5403	3102	3510
RMR011	R1930	4460	2375	337	3326	4628	2857	1777	3299	3661	2422
RMR011	R1940	1687	2227	2945	4072	2531	1983	2177	1665	1800	1438
RMR011	R1950	1468	1978	963	-9999						

APPENDIX 7

Statistical descriptions of the total tree ring-width chronology for yellow pines at Rainy Mountain.

Series identification, interval years from innermost ring to outermost ring, total number of years present in the series, correlation with the master chronology, and mean sensitivity (relative change in ring width from year to year)

Series		Interval		No. of Years	Correlation with Master	Mean Sensitivity
1	3P001	1944	2012	69	0.505	0.231
2	6P002	1937	2012	76	0.483	0.301
3	6P005	1933	2012	80	0.641	0.265
4	6P013	1934	2012	79	0.524	0.264
5	8P001	1944	2012	69	0.442	0.324
6	8P002	1933	2012	80	0.381	0.229
7	12P011	1935	2012	78	0.487	0.175
8	17P003	1940	2012	73	0.492	0.275
9	17P008	1966	2012	47	0.356	0.348
10	19P005	1946	2012	67	0.359	0.308
11	23P007	1933	2012	80	0.500	0.295
12	24P004	1950	2012	63	0.494	0.253
13	24P009	1924	2012	89	0.361	0.319
14	BTR006	1936	2012	77	0.482	0.233
15	BTR007	1920	1991	72	0.481	0.332
16	BTR010	1924	2012	89	0.527	0.270
17	BTR015A	1889	2012	124	0.584	0.302
18	BTR015B	1892	2012	121	0.720	0.297
19	BTR016A	1899	2012	114	0.536	0.258
20	BTR016B	1890	2012	123	0.636	0.242
21	BTR019	1916	2012	97	0.397	0.211
22	RMR005	1928	2012	85	0.584	0.305
23	RMR007	1925	2012	88	0.423	0.256
24	BTR017	1926	1993	68	0.311	0.354
25	11P009B	1892	2012	121	0.468	0.248
26	RMR005	1928	2012	85	0.584	0.305
27	RMR011	1914	1952	39	0.528	0.479
Total		**1889**	**2012**	**2253**	**0.505**	**0.278**

APPENDIX 8

Index chronologies for Rainy Mountain yellow pines

Standard, residual, and arstan index chronologies developed from yellow pines at Rainy Mountain, including 27 individual series in total. Indices are shown without decimal points, but the actual numbers can be found by dividing by 1000. Each row represents a decade, with a dimensionless index of tree growth listed for each year (mean=1000, or 1.0, indicating average growth).

Standard Index Chronology

Date	0	1	2	3	4	5	6	7	8	9
1889										1583
1890	882	1150	792	879	789	526	565	609	806	1200
1900	169	709	1036	548	913	1043	1263	1330	1204	1320
1910	1243	1173	1308	970	777	1357	1083	1067	876	941
1920	727	807	857	820	876	789	809	825	975	1249
1930	1342	976	662	784	852	850	925	892	1157	1016
1940	1110	1276	1177	1153	1050	946	1221	1059	1032	1200
1950	1121	1044	689	851	979	927	1152	1070	1251	1151
1960	957	786	955	776	755	716	718	1053	1182	1213
1970	895	1038	820	735	940	1208	941	1084	1002	783
1980	691	888	974	1039	987	1082	638	629	710	922
1990	1417	1471	1051	1106	986	836	865	1008	891	1015
2000	1060	900	879	914	1172	886	929	775	792	985
2010	1289	1454	1660							

Residual Index Chronology

Date	0	1	2	3	4	5	6	7	8	9
1890	991	1211	969	809	852	685	850	870	898	1418
1900	-93	1244	1158	513	1189	1137	1330	1105	1084	1113
1910	1093	909	1255	802	824	1461	892	1030	891	984
1920	748	893	933	837	1039	848	950	986	1054	1253
1930	1298	851	679	1022	966	994	998	985	1209	926
1940	1124	1198	1009	1045	959	911	1284	926	994	1174
1950	986	977	658	1030	1056	926	1202	955	1222	971
1960	862	808	1080	786	870	849	897	1195	1115	1110
1970	807	1061	773	829	1104	1178	755	1127	929	765
1980	808	1057	1006	1034	960	1088	613	824	937	1082
1990	1416	1202	774	1018	956	852	946	1075	876	1093
2000	1023	868	967	980	1234	766	968	823	919	1104
2010	1285	1266	1263							

ARSTAN Index Chronology

Date	0	1	2	3	4	5	6	7	8	9
1886							1583	882	1150	792
1890	785	1119	1050	880	806	569	644	763	883	1486
1900	258	856	1119	590	1096	1238	1471	1388	1204	1096
1910	1007	819	1116	864	759	1363	1103	1098	934	870
1920	658	716	840	836	1053	955	964	992	1049	1291
1930	1454	1059	628	725	776	931	1072	1098	1297	1077
1940	1115	1204	1050	1027	928	832	1191	1046	1030	1192
1950	1048	974	614	792	977	979	1278	1140	1276	1077
1960	817	652	861	752	819	848	883	1207	1281	1276
1970	924	931	669	624	956	1237	978	1159	997	712
1980	643	870	1002	1132	1101	1149	668	602	725	986
1990	1530	1577	1075	949	775	637	769	1019	982	1166
2000	1148	929	901	892	1170	888	920	791	801	1045
2010	1363	1509	1525							

VITA

Alex Dye was born and raised in Indianapolis, Indiana as the oldest of three children. He graduated from Cathedral High School in 2006, and earned a Bachelor of Arts degree in Geography from Indiana University-Purdue University Indianapolis in 2011. Following completion of his B.A., he continued his education in geography by pursuing a Masters degree at the University of Tennessee in Knoxville, focusing on dendrochronology and biogeography. While a student at UT, he worked for four semesters as a Graduate Teaching Assistant for physical geography courses. His research took place under the leadership of Dr. Henri Grissino-Mayer in the Laboratory of Tree-Ring Science. This research focused on the forest stand dynamics and fire history of the southern Appalachian Mountains, culminating in a thesis presented for the Master of Science degree in the spring of 2013.